Highlights in Space

PROGRESS IN SPACE SCIENCE, TECHNOLOGY AND APPLICATIONS, INTERNATIONAL COOPERATION AND SPACE LAW

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Progress in space science, technology and applications, international cooperation and space law

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INTRODUCTION

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space, and covers the period from 1 November 1993 through 31 October 1994. The first part of the report, on space technology, applications, international cooperation and space law, was prepared by the International Astronautical Federation (IAF). The International Institute of Space Law (IISL) provided input for the section on space law. The second part, which focuses on space science, was prepared by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the most prominent international experts from many countries have contributed to this comprehensive and authoritative survey. The infomation it contains reflects the wide range of space activities currently being conducted in many national and international space programmes. A list of contributors is located at the end of the report. This publication is being circulated only in the language in which the reports were prepared and submitted.

This review of recent developments in space science, technology, applications, international cooperation and space law is intended to provide information on these developments to a broad international audience. First published in 1992 as part of United Nations activities undertaken for International Space Year, the publication seeks to increase the awareness of all countries of the benefit of space activities.

It is hoped that this publication will make a significant contribution to the ongoing United Nations effort to disseminate information on space activities and to highlight the benefits they provide to all countries of the world.

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PART ONE:

HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS, 1994

I. OVERVIEW

The most significant development in space technology and applications during 1994 was the almost universal trend toward cooperative agreements, joint ventures, and mergers among both government institutions and commercial corporations, motivated primarily by financial constraints on all sectors in almost all the spacefaring nations. Perhaps the most visible of the cooperative government-to-government programmes was the agreement between the United States and the Russian Federation which has resulted in Russia becoming full partners with the United States, Europe (in the form of the European Space Agency, ESA), Japan, and Canada on the international space station effort, which also involves joint missions using the Russian Mir space station and the United States Shuttle. In the corporate category, by far the most important action was the purchase by Martin Marietta (United States) of General Electric Astro-Space (United States) and then General Dynamics Space Systems Division (United States), followed by the merger agreement between Martin Marietta and Lockheed (United States) that will create Lockheed Martin, the largest aerospace company in the world.

Another major trend in 1994 was the increasing use of smaller, less costly spacecraft for all space missions: scientific, commercial, and even military. A number of new programmes aimed at driving down spacecraft size, mass, cost, and development time were initiated. Perhaps the most visible of these was the United States Clementine mission to map the Moon using sensors originally developed for military purposes. Although a software failure prevented the spacecraft from completing the second phase of its mission, rendezvous with the asteroid Geographos, Clementine set precedents for project management, cost and development time reduction, and overall programme efficiency.

In the commercial world, the development of new capabilities and systems continued apace, especially in direct broadcast satellites, mobile communications, navigation and position location, and high resolution imaging of the Earth. In contrast to the constraints faced by most government space agencies and large aerospace contractors, financing for these activities has been readily available, mainly from system suppliers and other commercial sources. Sales of satellites, launches, and ground-terminal equipment from 1992 to 2004 (12 years) are projected to be as high as $113 billion, not including the already burgeoning sales of position-location instruments and hand-held telephone receivers. Of particular note is the decision by several governments to allow the commercial distribution of very high resolution images (down to 1 m), which has generated several new commercial entities and is likely to stimulate more in subsequent years. One sobering note, however, is that projections for growth of the mobile communications market imply that only two or three of the more than 12 currently proposed systems are likely to survive and prosper.

These developments in both technology and international cooperation have enormously expanded the opportunities for developing nations to reap the benefits of space technologies. In this context, the most important of the new technical developments are in direct broadcast satellites, communication via satellites with mobile receivers, navigation and position location, significantly better resolution and data processing of remote sensing imagery, introduction of radar imagery from space, and deployment of a whole new phalanx of environmental remote sensing instruments. In international cooperation, the most significant implications to developing nations are the proliferation of joint ventures between and among private corporations and government organizations, expansion of international involvement by the former Eastern bloc nations, and intensification of cooperative satellite environmental monitoring and research activities worldwide.

The major technological feat of the year was the repair of the Hubble Space Telescope (HST) by the crew of United States Shuttle Endeavour, who carried out the longest and most successful extra-vehicular activity ever. They replaced the spacecraft's European-built solar arrays and the wide-field planetary camera; installed corrective optics for the spacecraft's other three instruments to compensate for the primary mirror's aberration; installed new stabilizing gyroscopes (three had failed); replaced miscellaneous electronic controls, Earth-sensing magnetometers, a solar array controller, and a spectrometer power cable; and installed additional computer memory. All the replacements and repairs proved to be fully successful, and restored the telescope's capability up to the limits of its design.

One of the year's space highlights was undoubtedly the spectacular collisions of the fragments of comet Shoemaker-Levy 9 with Jupiter, which occurred almost coincidentally with the 25th anniversary of the first human landing on the Moon. Although hundreds of ground-based and Earth-orbital instruments were focused on the giant planet during the collisions, because they took place on the far side of Jupiter, the Galileo spacecraft, which was on its way to Jupiter, had the only direct view of the impact sites. Its instruments and camera recorded invaluable data on the results of the collisions, many of which are still in the process of being transmitted from the spacecraft's remaining low-power antenna.

II. SPACE TRANSPORTATION

A. Current Launch Activities

The spacefaring nations conducted 83 launches in 1993, the last full year for which figures are available; 79 were successful. Again the Russian Federation led the world with 48 (six Proton, of which one failed, two Zenit, 18 Soyuz, six Cosmos, seven Tsyklon, eight Molniya, and one Start). The United States was next, with 25 (seven Space Shuttle, one Titan-4 (which failed), five Atlas-Centaur (of which one failed), seven Delta, one Atlas-E, one Titan-2, one Scout, and two Pegasus. Europe launched seven Ariane-4, China one Long March-2C, Japan one M3S2, and India one Polar Satellite Launch Vehicle (PLSV), which failed.

The United States McDonnell-Douglas Delta-2 orbited a Global Positioning Satellite (GPS-5) in October 1993, NATO-4B in December, Hughes Communications' Galaxy-1R in February, GPS-6 on 9 March, and NASA'S WIND on 1 November, bringing the vehicle's success string to 49 in a row. Delta's overall launch record to date is 215 of 227 (94.7 per cent), with 92 of 93 (98.9 per cent) since 1977. The POLAR spacecraft launch aboard Delta is scheduled about a year later. Delta launches of Radarsat and XTE are planned for 1995. Options have been exercised by NASA for Delta launches of the Near Earth Asteroid Rendezvous (NEAR) mission in first quarter of 1996, the Mars Pathfinder in December 1996, and the Mars Global Surveyor in November 1996. Launch of the MSX (Mid-course Space Experiment) is scheduled from Vandenberg Air Force Base (VAFB) by the end of the year; it will be the first Delta launch from VAFB since the Cosmic Background Explorer (COBE) in November 1989. For the commercial market, McDonnell Douglas signed a contract on 14 April 1994 with Motorola for Iridium launches. Delta rockets will be used to launch 40 of the 66 required satellites, five at a time in eight launches from VAFB between 1996 and 1998.

The United States Martin Marietta (formerly General Dynamics) Atlas-Centaur launched the United States Air Force's Defense Satellite Communications System (DSCS-3 F4) in November 1993, AT&T's Telstar-401 in December (the first solid-rocket-boosted Atlas-2AS), the National Oceanic and Atmospheric Administration's (NOAA's) GOES-8 satellite on 13 April 1994, a United States Navy Ultra-High Frequency Follow-On satellite (UHF-F3) on 24 June, the Hughes DirecTV satellite DBS-2 on 3 August, and Intelsat-703 on 6 October, bringing Atlas-Centaur's overall launch success record to 71 of 85 (83.5 per cent). Eleven Atlas-Centaur launches are planned for 1995. Under Martin Marietta's Intermediate Expendable Launch Vehicle (IELV) contract with NASA, signed in February, an Atlas-2AS will launch the Earth Observing System (EOS-AM-1) satellite in 1998 and NOAA's GOES-L (if needed) in 2000. The contract also includes options for seven more launches. Launch facilities at VAFB (SLC-3E) are now being modified for Atlas-Centaur launches. An Atlas E successfully launched an 800 kg Defense Meteorological Satellite Program (DMSP) spacecraft from VAFB into an 840 km polar orbit on 29 August.

The United States Martin Marietta Titan-4 launched the United States Air Force's 4550 kg, $1.4 billion Milstar-1 on 7 February 1994. It was the first flight of the Titan-4/Centaur, which carried the heaviest payload ever launched to geostationary orbit and used the largest payload fairing to that date, the 23 m model. Titan-4 also launched a United States military satellite on 3 May, featuring the first use of the 26 m payload fairing, the largest in the inventory. The launch ended a record 1,054 days of delay due to various reasons. Another military satellite was the payload for the third successful Titan-4/Centaur launch this year, on 27 August; it was the ninth success (of ten attempts) for the Titan-4. A fourth launch attempt on 26 September was postponed until November due to contamination that settled on the Defense Support Program payload. In January a refurbished Titan-2G vehicle launched the Clementine satellite (see below) from VAFB.

Orbital Sciences Corporation's Pegasus (United States) launched the United States Defense Department's Space Test Program (STEP-2) satellite in May 1994, and although the launch was successful, the satellite ended up in a lower-than-planned orbit due to problems with the fourth stage. The new Pegasus-XL, the first to use the Orbital Sciences modified L-1000 "Stargazer" aircraft, was destroyed by the range safety officer 2.5 minutes after its launch on 27 June when the second stage failed to ignite. The problem was later identified as a basic design flaw that caused aerodynamic instability, probably as a result of too heavy reliance on computational fluid dynamics and not enough actual wind tunnel testing. The XL has extended-length first and second stages, allowing it to carry 25 per cent more propellant than the standard Pegasus. A standard Pegasus, the last to use the B-52 aircraft, was subsequently launched successfully on 3 August, orbiting the United States Defense Department's Advanced Photovoltaic and Electronics Experiment (APEX) satellite. This spacecraft was the first to use the Pegastar platform that shares guidance and control, power, communications, and data systems with the Pegasus third stage, boosting the vehicle's payload capability and cutting costs. The overall flight record for the standard Pegasus is now six successes in seven launches (85.7 per cent).

After numerous delays, Orbital Sciences' Taurus had a successful maiden launch on 13 March from VAFB. The prototype version of the vehicle used an MX missile first stage in place of the Thiokol Castor-120 which will be used on future flights. The launch placed two United States Defense Department satellites, a Darpsat and a solar-powered STEP satellite carrying the experimental Technology for Autonomous Operational Survivability (TAOS) payload (see below), into a circular polar orbit. The Advanced Research Projects Agency (ARPA) has options for four more Taurus launches, but no commercial launch commitments have yet been obtained.

The last Scout in NASA's inventory was successfully launched from VAFB on 8 May 1994 with the Ballistic Missile Defense Organization's (BMDO's) Miniature Sensor Technology Integration (MSTI-2) satellite. The satellite achieved about 99 per cent of its mission objectives (testing advanced missile-detection sensors) before an electrical problem caused loss of contact early in September. The launch was the 25th success in a row for Scout (no failure since 1975), whose 34-year record was 62 successes of the last 63 (98.4 per cent) going back to 1967, and 88 of 91 (96.7 per cent) going back to 1964. Scout's overall record was 104 success out of 118 attempts, or 88.1 per cent.

In Europe, Arianespace closed out 1993 with three successful launches: V-60 in October (Intelsat-701), V-61 in November (Mexico's Solidaridad-1 and MOP-3), and V-62 in December (Hughes Communications DirecTV-1 and Thaicom-1). After 26 launch successes in a row, however, this year's initial launch attempt, V-63 on 24 January 1994, ended prematurely as a third stage failure sent the Aerospatiale Eutelsat-206 and Turksat-1A satellites into the ocean. The failure, which occurred about 80 seconds into the third stage burn, was later attributed to an overheated bearing on the liquid oxygen side of the propellant turbopump. Flights resumed on 17 June with the launch of an Intelsat-7 satellite (702), which also carried two mini-satellites for the United Kingdom Ministry of Defence. Subsequent flights orbited the second PanAmSat satellite, PAS-2, and the Japanese Broadcast Satellite (BS-3N) on 8 July, and the Brazilsat-B1 and Turksat-1B satellites on 10 August. The apparently successful launch of AT&T's 3300 kg Telstar 402 satellite by Ariane V67 on 8 September was followed by total loss of contact with the spacecraft only 10 minutes after separation from the launcher, apparently due to propellant leakage from the onboard propulsion system. Ariane V68 (a 44L configuration) subsequently launched Mexico's 2,700 kg Solidaridad-2 and Thailand's 1,080 kg Thaicom-2, both built by Hughes, on 7 October.

Despite the time lost due to the 24 January 1994 failure, Arianespace's target is still to conduct 30 launches in the next three years, with a full manifest through 1996 and 1997 rapidly filling up. A total of 16 launch contracts were signed during 1993, about 75 per cent of last year's available commercial launch opportunities. Six more launch contracts were signed in 1994, and contract negotiations for eight more are in progress. Arianespace revenues in 1993 were $700 million, and the company's backlog is currently 40 satellites worth over $3.3 billion. Ariane's reliability record is now 31 successes of the last 32 attempts (96.9 per cent), 38 of 40 for Ariane 4 (95 per cent), and 62 of 68 (91.2 per cent) overall.

In the Russian Federation, 31 launches have been conducted through October 1994, with only one failure (a Tsyklon, in May). Nine of the launches were Protons, whose overall record is now 36 successes of the last 37 (97.3 per cent), 52 of the last 54 (96.3 per cent), and 199 of 225 (88.4 per cent) overall. Launches scheduled for November and December 1994 included an Express communications satellite, an Ekran television broadcast satellite, a Raduga communications payload, and a data-relay satellite similar to Russia's Altair. A launch contract is now in place for the Inmarsat-304 launch in 1996, and Motorola is planning to use at least two Protons to launch part of the Iridium constellation. On 7 October Societé Européenne des Satellites opened negotiations for a Proton launch of Luxembourg's Astra-1F early in 1996, with an Ariane launch still an option. In April, Zenit launched a Kosmos early-warning satellite and on 26 August a new military satellite was launched, bringing its reliability record to 18 out of 21 (85.7 per cent).

On 10 October, the Russian Space Agency (RSA) laid out a detailed launch plan through 2005 for over 100 meteorological, remote sensing, and communications spacecraft, including six weather satellites (Meteor-3s, Meteor-3Ms, and geostationary-orbit Elektros), at least seven remote sensing satellites (Resurs-01s, Resurs-02s, Okean-01s, Okean-0s, Nika-Kuban), many geostationary orbit communications satellites (3 Gorizonts, 9 Expresses, 3 Express-Ms, four direct-broadcast Ekran-Ms, 2 advanced direct-broadcast Gals, 3 Arcos), four Molniya-orbit Mayak spacecraft, and two multi-satellite low-orbit communications systems (12 developmental Gonets followed by 30 operational Gonets, and 48 Signel satellites).

The new era in space cooperation between Russia and Ukraine was highlighted by the launch on 11 October of the Ukraine's oceanographic satellite, Okean-O1 No. 7, by the Russian Space Forces aboard a Ukrainian Tsyklon-3 rocket from Plesetsk, in Russia, under contract to the RSA. Okean-O1 carries a side-looking radar with 3.15-cm wavelength for all-weather monitoring of sea surfaces to measure ice cover, sea roughness, and wind speed.

The LKE International organization, formed last year by Lockheed (United States), Khrunichev, and Energia to market the Proton, has signed up to five future launches for Space Systems/Loral (one firm and four options) and another for SeS/Astra. Khrunichev Enterprises, an investor in the mobile-satellite communications company Iridium (United States), has also secured an agreement to launch 21 Iridium satellites aboard three Proton launches from Baikonur Cosmodrome.

Disagreements between Russia and Kazakhstan over the use of the Baikonur Cosmodrome, which had threatened disruption of Russian launch activity, were settled on 28 March with the negotiation of a 20-year lease plus an option for an additional 10 years. The lease, signed in late 1994, places both the Cosmodrome site and the surrounding city of Leninsk under Russian sovereignty and jurisdiction. The Russian Military Space Forces will continue to operate the space launch facility.

New cooperative ventures initiated in 1994 included the teaming of NPO Yushnoye (Ukraine), Boeing (United States) and NPO Energia (Russia) on a sea-launched, upgraded Zenit rocket, an agreement between Khrunichev Enterprises and Deutsche Aerospace for joint production and marketing of launch services using a "Roket" derived from converted SS-19's, and several propulsion-related efforts (see below). The Boeing-NPO Yushnoye-NPO Energia joint venture plan, announced in June, is to develop, build, and market an upgraded Zenit rocket as a commercial launcher. The upgrade would consist of adding a Block DM upper stage (Proton's fourth stage) to the Zenit, enabling it to carry 16,000 kg to low Earth orbit and 6,000 kg to geosynchronous transfer orbit -- the same as Ariane 5. The current two-stage Zenit can lift 13,500 kg to low Earth orbit. The vehicles would be built in Ukraine and Russia and shipped to a Boeing plant in the United States (Florida or California) for assembly and testing. Launches would be from a floating platform towed into international waters.

The National Space Agency of Ukraine announced on 26 September 1994 the signing of an agreement for regular use of Zenit rockets to launch Russian military and space-station payloads. The first launch under the agreement will carry a Progress supply vehicle from Baikonur Cosmodrome to the Mir Space Station in 1996. It is estimated that Russia will need two to three Zenits per year.

McDonnell Douglas (United States) announced on 21 August the signing of cooperative agreements with Russia's Centralized Special Design Bureau in Samara for cooperative work on launch vehicle stages, ground support systems, and components, and with the Central Research Institute for Special Machine Building in Khotovo for composite structures, fabrication techniques, and materials.

The Swedish Space Corporation (SSC), signed a joint venture agreement in June with STC Komplex, developer of the Start-1 conversion of the Russian SS-25 missile. This agreement supersedes a prior SSC arrangement with the Norwegian Space Center to launch from Andoya using a new vehicle that was to be developed by PacAstro (United States). The new agreement includes SSC-funded upgrades to the Pletsesk launch site. SSC plans to initiate polar-orbit launch services late in 1994 at a rate of about one per year at first, increasing in subsequent years. The four-stage Start-1 flew once as a civil launcher, in March 1993. It can lift 300 kg to a 750-km polar orbit; a later five-stage version is planned for carrying 500 kg payloads to the same orbit.

On 8 February, China conducted the first launch of a new Long March configuration, the CZ-3A. This vehicle is designed to put a 2.4 tonne satellite into a geosynchronous transfer orbit (GTO); the initial mission, launched from Xichang, carried the SJ-4 space environment research satellite and a simulated communications satellite. The second CZ-3A launch of 1994 took place on 21 July, when the Apstar-1 satellite was successfully orbited (see below), and the third took place on 28 August with the successful launch of Australia's Optus B-3. Also in July, a CZ-2D successfully orbited an FSW recoverable scientific satellite. The Chinese launch programme seems to have recovered from the explosion at the Xichang Satellite Launch Center on 2 April, which destroyed the $35 million Feng Yun-2 (Wind and Cloud) meteorological satellite, killed one worker, and injured 20 others. Launches planned for the balance of this year include Apstar-2 and the Chinese domestic communications satellite, DFH-3.

For future years, China's Great Wall Industries has agreements to launch the Space Systems/Loral Intelsat-708A satellite and the Martin Marietta Intelsat-801 and Asiasat-2 satellites. On 6 January 1994, the U. S. government approved the export of Asiasat-2 and also (in July) two Echostar broadcast satellites for Chinese launches; approvals for launching Australia's Optus B3 and Apstar-2 were granted in March. Hughes has been negotiating an agreement with the Chinese for up to ten future launch options. China Great Wall Industries, an investor in the Iridium mobile communications satellite enterprise, also has a firm contract to launch ten Iridium satellites aboard five as-yet undesignated rockets beginning in late 1996. All current Chinese launch contracts are subject to continued successful development of the CZ-3A and CZ-3B vehicles. The overall Long March launch record currently stands at 31 successes out of 35 attempts (88.6 per cent).

China expects to launch 30 satellites for foreign customers by 2000. It is working on an upgraded version of the CZ-3A, called the Long March-3B, which will be able to launch up to 4.8 tonne satellites, and also on the CZ-3C, which uses strap-on boosters, the CZ-4B, which eliminates the cryogenic engines used on the CZ-3 series, and a small launcher (CZ-1D) to lift 1-tonne payloads at low cost (about $10 million).

The first major Japanese launch in two years took place on 4 February 1994, with the long-awaited first flight of the National Space Development Agency's (NASDA) H-2 vehicle from Tanegashima Space Center. The successful launch, the 25th in a row of Japan's large (N-1, N-2, H-1, and H-2) vehicles, carried the Vehicle Evaluation Payload (VEP) and the Orbital Re-entry Experiment (Orex).

H-2 also attempted to launch Engineering Test Satellite (ETS-6) on 18 August, but was shut down by a faulty ground-based countdown sequencer six seconds before the solid boosters were to fire. The satellite was subsequently launched successfully on 23 August, but failure of the apogee kick engine kept ETS-6 from reaching its desired geostationary orbit (see below). H-2 is scheduled for a dual launch of the Space Flyer Unit (SFU) and Geosynchronous Meteorological Satellite (GMS-5) in February 1995, followed by the Advanced Earth Observing Satellite, ADEOS-1. Japan plans to launch seven satellites with H-2 in the next three years. The vehicle can carry 2 tonnes into the geostationary orbit.

Failure of India's first Polar Satellite Launch Vehicle (PSLV) launch attempt in September 1993, which carried the Indian Remote Sensing satellite IRS-1E, was subsequently attributed to a software error in the guidance and control processor resulting from an anomalous second-third stage separation. The PSLV's six S-125 660-kN thrust solid-rocket strap-on boosters, its PS-1 4.5-MN thrust solid-propellant core, its 720-kN thrust L-33 liquid-propellant second stage (nitrogen tetroxide and unsymmetrical dimethyl hydrazine), its 340-kN thrust third-stage solid rocket, and other subsystems operated satisfactorily.

The next PSLV launch, of the 800 kg IRS-P2 remote-sensing satellite into a 98.6 degree, 825 km orbit, was conducted successfully on 15 October. This success will allow India to stop contracting with Russia for launches after completion of two already-committed IRS-2 launches by Vostok rockets in 1995. The Indian Space Research Organization (ISRO) also announced that the PSLV would now be available on the international commercial market for launching payloads in the 1,000 kg class at a price of about $25 million, considerably less than that charged by competitive launchers. ISRO plans to equip the PSLV for launching multiple payloads (up to three at a time) and to expand its capability to about 1,300 kg.

On 4 May, India conducted a successful launch (the first in four attempts) of the Augmented Satellite Launch Vehicle (ASLV), placing into an elliptical (440 x 930 km) orbit the 114 kg Stretched Rohini Scientific Satellite (SROSS-C2). The satellite's two payloads, a Gamma-Ray Burst Experiment and a Retarding Potential Analyzer to measure helium and hydrogen densities in the Earth's ionosphere and thermosphere at low latitudes, were both successfully operated by 11 May.

B. Development Activity

In the United States, Lockheed continues to develop the Lockheed Launch Vehicle (LLV) family. On 30 June 1994, United Technologies Chemical (UTC) Systems successfully test-fired the second-stage Orbus 21D solid rocket motor. The smallest vehicle of the family, the LLV-1, can carry a payload of 1100 kg into low Earth orbit (185 km). It is targeted for a first launch from VAFB in December 1994; the payload is a CTA, Inc. (United States) satellite. Launch arrangements are in place to use Space Launch Complex (SLC)-6 at VAFB. Lockheed is negotiating with customers for the second and third flights. The company is also continuing development of the larger LLV-2 and LLV-3 vehicle configurations, which can carry up to 4,100 kg to low Earth orbit. All the LLVs use combinations of Thiokol Castor-120 and UTC Orbus-21D solid rocket motors.

After having been grounded in October 1993 due to lack of funding following three successful flights, the McDonnell Douglas DC-X reusable vehicle continued operations this year with NASA and then Department of Defense funding support. A successful 136-second suborbital test flight was conducted on 20 June; the vehicle reached an altitude of 870 m and flew at angles of attack from 0 to 70 degrees. During the next flight, on 27 June, an explosion in the ground propellant vent system, external to the vehicle, occurred at lift-off. The vehicle rose and then was successfully landed about 78 seconds later in the desert, off the launch/landing pad, by its emergency auto-land sequence. A 4.5 x 1 m hole was then discovered in the aeroshell.

McDonnell-Douglas subsequently (in August) received a $17.6 million contract from NASA (the company will also invest $7.6 million of its own funds) to convert the vehicle into a flight-test article, DC-XA, for advanced technologies such as composites and aluminum-lithium tanks (see below). McDonnell Douglas later signed agreements with NASA to build and test two cryogenic fuel tanks, a graphite epoxy intertank linking the hydrogen and oxygen tanks, and a device to convert liquid to gaseous hydrogen for the flight control system, and also to test a Russian-designed graphite intertank. The DC-X programme was designed to test operational features of reusable launchers, not the performance requirements of single-stage orbital flight.

NASA announced plans for two new expendable launch vehicles to satisfy its needs for launching "Ultra-Lite" and "Medium-Lite" payloads. The Ultra-Lite launch class is defined as 225 kg to low Earth orbit at 28.5 degrees, or 135 kg into low polar orbit, at a cost of $5-7 million. NASA plans an average of about two missions per year beginning in 1998. The Medium-Lite vehicle would fill the gap between existing small and medium launchers; that is, about half Delta's capability: 2,250-3,600 kg to low Earth orbit at a cost less than $35 million. The first firm Med-Lite launches would probably be Mars Landers in 1998. NASA plans an average of two launches per year from 2000 to 2010, mainly for Discovery and Explorer spacecraft. The draft Request for Proposals, issued 27 September, calls for five firm Medium-Lite launches and up to nine options, with a guideline price of $30 million per launch.

Various United States agencies conducted a number of studies aimed at defining the nation's future in space transportation. On 9 March, NASA released a study called "Access to Space" examining three options: (1) use the Shuttle essentially "as is" until 2030; (2) replace it with a vehicle based on conventional technology in 2005; and (3) replace it with a vehicle based on advanced technology in 2008. The agency selected the third option, which focuses on reusable-vehicle technologies (including but not limited to single-stage-to-orbit designs).

The United States Department of Defense (DOD) conducted a "Space Launch Modernization Study" led by General Thomas Moorman, currently United States Air Force Vice Chief of Staff. That study, completed in May, outlined four options: (1) sustain existing Delta, Atlas and Titan rockets, (2) evolve a new expendable rocket from the existing ones, (3) develop a "clean-sheet" expendable rocket (for example, like last year's "Spacelifter") to replace the existing fleet, and (4) develop an advanced-technology reusable launch vehicle. The recommended approach currently appears to be option (2), termed an "Evolved Expendable Launch Vehicle" (EELV), but a final decision on the DOD's space launch plans has yet to be made.

In a third study, approved for release by United States President Bill Clinton on 5 August, the president's Office of Science and Technology Policy defined a new national space transportation policy and strategy. It also identified three options: (1) keep existing expendable launch vehicles and the Shuttle, with improvements, (2) develop an evolutionary, rather than a new expendable launch system using current technology, and (3) use advanced technologies to develop a fully reusable vehicle. The policy statement assigns option (2) to the DOD option (3) to NASA, with both agencies directed to seek innovative cooperative mechanisms with industry to carry out their assignments. Their implementation plan was due on 5 November.

On 29 September, NASA notified industry of its intent to issue a Cooperative Agreement Notice for an advanced technology demonstrator (ATD), designated X-33, to serve as an integrated flying testbed for advanced reusable launcher technologies. Key technologies identified by NASA during a 19 October industry briefing included reusable cryogenic tanks, graphite composite primary structure, durable thermal protection systems, reusable propulsion systems, autonomous flight controls, and readily operable systems. Following the X-33 flight-test programme, NASA also announced its intent to contract for the X-34, defined as a small reusable orbital booster that will both demonstrate advanced technologies and provide the United States launch service industry with a vehicle able to lift up to 2,000 kg to low Earth orbit. Its first flight is planned for 1997, with the first orbital launch in 1998.

Potential industry candidates for the X-33 and X-34 include McDonnell Douglas's Delta Clipper, based on the DC-X (see above); Lockheed's aero-ballistic rocket, a vertical takeoff, horizontal-landing (VTOHL) SSTO design; Rockwell's wing-body launcher, also a VTOHL SSTO concept; and the Martin Marietta-Aerojet Strutjet vehicle, currently conceived as a VTOHL single-stage or two-stage design. Meanwhile, a small United States company founded in October 1993, Kistler Aerospace Corporation, began assembling a subscale SSTO demonstrator in midyear for a scheduled launch in the spring of 1995. In September, Kistler announced plans to develop subsequent full-scale suborbital and orbital vehicles without support from the government.

In Europe, Ariane 5 continues on a tight schedule towards an October 1995 initial launch that will carry ESA's four-satellite Cluster scientific mission. The payload for the second demonstration flight (scheduled for early 1996), originally planned to be the Artemis experimental data-relay satellite, had to be changed due to technical difficulties with the spacecraft's laser optics system. That flight is now planned to launch the Arabsat-2 communications satellite, an amateur radio satellite, and an atmospheric re-entry experiment (see below). The Ariane 5 fairing has been successfully tested at the NASA facilities in Ohio, and most of the ground facilities at Kourou have been completed. Engine testing is on schedule despite an explosion that occurred 15 seconds into a planned 320 second ground test of the Vulcain main-stage engine on 12 April (see below). A successful firing on 20 June of the 237-tonne, 5.9-MN thrust solid-rocket booster also resolved earlier problems with propellant consistency.

On 1 January, ESA received sufficient commitments from its member states to allow it to undertake Festip, a three-year study of reusable launchers. It is estimated that the study will cost $40 million. France did not participate in the initial subscription due to its earlier (1991) commitment to a national hypersonic technology programme called Prepha, which is expected to cost $85 million over five years.

A European Small Satellite Missions Initiative was proposed in May by Eurospace, a Paris-based organization that represents 30 European space companies. The initiative seeks annual funding of $117 million from ESA to develop a new small-satellite launcher to compete with several United States firms building small launchers. The proposed funding includes the cost of development plus 25 launches.

Aerospatiale (France) and the Central Specialized Design Bureau of Samara (Russian Federation) are exploring a joint new launcher concept based on a Soyuz-derived first stage and an Aerospatiale cryogenic upper stage. The French space agency CNES also announced on 22 March that it is studying a small three-stage, low-cost (below $20 million per launch), solid-propellant launcher for 1-tonne payloads to 700 km orbits, and that the agency still plans to implement improvements to Ariane-5 that will boost its geostationary-orbit payload capacity from 6,000 to 7,400 kg by 2001.

In November 1993, the RSA announced cancellation of plans to build the Energia-M, a smaller version of the Energia. Instead, the agency announced in August that its next heavy-lift launcher would be based on the Khrunichev State Space Science and Production Center's Angara-24. The two-stage vehicle would use the Zenit's RD-170 engine for its first stage and modified Proton hardware for the second, with a Proton-specific Block-D (Energia) kick stage to be built by NPO Energia. Performance specifications call for delivering a 22-tonne payload to a 200 km orbit at 63 degrees inclination, which implies launches from the Plesetsk Cosmodrome in Russia rather than Baikonur in Kazakhstan. RSA requirements also specify non-toxic propellants, necessitating a change in the second-stage Proton engine, which burns nitrogen tetroxide and unsymmetrical dimethyl hydrazine. The agency also confirmed that the Buran reusable winged spacecraft would not fly again.

Development efforts on the three-stage M-V vehicle by Japan's Institute for Space and Astronautical Sciences (ISAS) continued, with operational capability targeted for 1996. Successful test firings of the first and second stage rocket motors were conducted in June and March respectively; further testing is planned for summer of 1995. A test of the kick-motor is planned for late 1994.

On 1 August, Japan's NASDA endorsed a long-range plan developed by the Mitsubishi Research Institute for a Fully Reusable Space Infrastructure programme that would include an unpiloted shuttle, six orbital transfer vehicles, seven orbiting robot fuel stations, and various service vehicles and systems. Projected missions for the 2010-2020 time frame, besides launches to the space station and to the Moon, include the servicing of satellites in various orbits and on-orbit assembly and repair, replacement, or recovery of space platforms as well as lunar and planetary surveyors. Total investment cost for the infrastructure is projected at about $46 billion, but the study estimated that it would cut space operating costs by a factor of ten.

India is continuing development of the Geostationary Space Launch Vehicle (GSLV). In June, there was a successful test firing of the first stage cryogenic engine under development. Until that engine is available, India will obtain seven cryogenic engines from Russia, with the first delivery scheduled for 1996; however, technology is not included in the agreement.

Israel revealed plans on 11 October for a new launcher, Next, as a candidate for NASA's Ultra-Lite competition (see above). The four-stage successor to Israel's three-stage Shavit, which will launch Israel's third Ofeq satellite in 1995, can lift 300 kg payloads into polar orbit from the VAFB launch site in the United States. Launch cost per spacecraft, based on a dual launch, would be less than $6 million.

III. UNMANNED EARTH ORBITAL ACTIVITIES

A. Telecommunications

1. Fixed-Base Communication Systems

On 27 October 1993, a landmark agreement was signed at the International Telecommunications Union (ITU) in Geneva by the governments of Tonga and Indonesia. Following a bitter months-long dispute, the governments agreed to share the geostationary orbital position at 134 degrees east. The slot is occupied by Palapa's Pacific-1 satellite, owned by Indonesia's Pasifik Satelit Nusantara, and Tongastar-1, a leased Russian Gorizont satellite operated by Rimsat Ltd. of the United States. Under the agreement, Palapa will use the slot until Pacific-1 stops operating, which is expected to be in October 1995.

PanAmSat, which competes with Intelsat in the international satellite communications market, announced on 3 December 1993 the signing of contracts totaling $958 million for about 30 per cent of the capacity of its three new 1800 kg Hughes HS-601 spacecraft, to be launched by Arianespace in 1994 and 1995. Each satellite carries 16 C-band and 16 Ku-band transponders, two-thirds of which will be dedicated to television transmissions. The new PanAmSat customers, Turner Broadcasting, ESPN, and ABS-CBN Broadcasting of the Philippines, will reach receivers in the Asia-Pacific region via PAS-2, North and South America, Africa, and Europe via PAS-3, and the Indian Ocean via PAS-4. PAS-1 was launched in 1993. PanAmSat's financing of $720 million for the supplementary system, which also includes a fourth ground spare satellite, has been secured.

Hughes Communications filed an application with the United States Federal Communications Commission (FCC) on 8 December 1993 for a two-satellite system to provide businesses with video telephone and high-speed data services. The Spaceway system, expanded on 28 July to a nine-satellite, global $3.2-billion network, will provide interactive (2-way) video, audio, and data to schools, businesses, and individual households at rates up to 1.5 mb/s (100 times faster than by telephone), using low-cost 66-cm antennas. It will use advanced technologies such as Ka-band transmission, digital compression, onboard digital processing and switching derived from military satellite programmes, and 48 tightly focused spot beams to cover the entire United States land area. Service is expected to begin in 1998, with ground stations (including the 66 cm diameter dish antennas) costing about $1,000 and service charges of about $1 per minute. Spaceway operations, expected to be up to full capacity by 2000, are projected to be much less expensive than those of comparable systems; for example, it is claimed that a 30 minute Spaceway video teleconference will cost only about $6. One Spaceway service, called Galaxy Classroom, will use both existing and planned satellite communication systems to deliver educational services directly to schools.

On 17 December 1993, the first United States domestic direct broadcast satellite, DBS-1, was launched by Arianespace; the second, DBS-2, was launched on 3 August by a Martin Marietta Atlas-2A. Owned by DirecTV and United States Satellite Broadcasting, the first of the Hughes HS-601 spacecraft, each of which is equipped with 16 120-W transponders, began broadcasting television programmes on 17 June to individual United States homes equipped with 45 cm diameter dish antennas. It is estimated that 750,000 receiver stations will be sold for about $700 each during the system's first year of operation. Combined, DBS-1 and DBS-2 are expected to deliver 150 channels of television programming to their customers. A competitive United States direct-broadcast system is planned by Primestar Partners (United States), which announced in March that it had secured $565 million in financing to buy two high-power broadcast satellites being built by Space Systems/Loral for Tempo Satellite Inc., the first of which is scheduled to be launched in mid-1996. Another United States competitor is Echostar Communications, whose two direct-broadcast satellites are being built by Martin Marietta Astro Space for launch in 1995 and 1996.

Besides Spaceway and DirecTV, Hughes announced on 3 May its involvement in another new venture. Its Digital Cinema programme will provide satellite-to-theatre delivery of cinema shows by converting the cinema films to digital high-definition television signals and beaming them via satellite to theatres. The movies can be stored in digital form at the theatres until ready for use. Special high-brightness projectors built by Hughes currently sell for $50,000 - $80,000 and about 100 are expected to be in operation by the end of 1994, mostly in Asia and Latin America.

Hughes Communications also announced on 3 October the formation of a partnership, Galaxy Latin America, comprised of companies from Brazil, Mexico and Venezuela. The system will use a modified version of the Hughes Galaxy-3R United States domestic communications spacecraft, now scheduled for launch in September 1995, to deliver direct-to-home Spanish-language television in Latin America. The service will emphasize educational broadcasts.

NASA announced on 21 March that its constellation of three fully functional and two partly functional Tracking and Data Relay Satellites (TDRSs) would be opened to industry users for testing new technologies. Potential experiments include measuring the quality degradation resulting from data compression or special coding in mobile satellite communication systems. The TDRS system operates at lower frequency bands than NASA's other orbital test facility for industry communication experiments, the Advanced Communications Technology Satellite (ACTS), which was launched in 1993.

Geomagnetic disturbances and electrostatic discharges caused by a sudden increase in solar wind electron flux on 20 January incapacitated the primary momentum wheels that stabilized both of Canada's Anik satellites. Ground controllers were able to regain control of Anik-E1 using its backup momentum wheel, restoring it to commercial service six hours after the failure of its stabilizing system, but the backup wheel on Anik-E2 did not respond to corrective efforts. Telesat Canada engineers, with the help of Martin Marietta (the satellite's manufacturer), developed a ground loop attitude control system using Anik-E2's onboard thrusters and magnetic torquers to control the satellite's attitude. A ground-based radio-frequency sensor was needed to provide the satellite with yaw information. The system was operated successfully on 21 June, five months after the failure occurred, and Anik-E2 was back in full commercial service on 1 August. This was the first time such a system had been devised for an operating, on-orbit satellite. The same storm caused Intelsat-K to wobble, resulting in a brief service outage, but the Intelsat spacecraft, which is designed for protection against electrostatic discharges, was quickly returned to service.

On 15 December, Sweden's Nordiska Satellitaktiebolaget (NSAB) completed the purchase of British Satellite Broadcasting's Marco Polo-1, now renamed Sirius. After moving the 5-channel direct-broadcast satellite from 31 degrees west to 5 degrees east, where it joined the 3-channel Tele-X, NSAB began operations in March to help serve the estimated 500,000 direct-broadcast satellite dishes in Scandinavia. The Scandinavian market is expected to grow to over 1.2 million by 2000.

At a 28-29 March meeting of Eutelsat's Board of Signatories, the 39 nation organization decided to award the contract for the Hot Bird Plus direct-broadcast satellite to Matra Marconi Space (France). The $220-million contract, signed in mid-April, calls for delivery and launch of a single 2,900 kg spacecraft to a geostationary-orbit slot at 13 degrees east longitude by mid-1996, although the launch vehicle has yet to be selected. The power-generating capacity of Hot Bird Plus will be 5.5 kW.

In early October, Eutelsat also solicited bids for up to seven Eutelsat-3 spacecraft, successors to the four Eutelsat-2 satellites currently in orbit. The 3-tonne spacecraft, the first of which is planned for launch near the end of 1997, will each carry 24 72-MHz transponders. In addition to European suppliers, Eutelsat solicited bids for the first time from manufacturers in the Russian Federation, a newcomer to membership in Eutelsat (see below), and from companies in the United States.

The Russian Federation's first direct-broadcast satellite, Gals-1, was launched to a geostationary orbit slot over the Indian Ocean from Baikonur Cosmodrome on 20 January aboard a Proton rocket. It is the first of five Gals spacecraft, built by NPO Applied Mechanics, slated for three geostationary orbit slots over Africa and two over the Indian Ocean, that will provide television broadcast services in the former Soviet Union to ground antennas 0.6 - 1 m in diameter.

The 2-tonne Japanese Engineering Test Satellite ETS-6, named KIKU-6, was successfully launched by the second H-2 vehicle into a geosynchronous transfer orbit on 28 August, after the initial launch attempt on 18 August was scrubbed due to a faulty ground control mechanism. However, when mission controllers attempted to initiate the spacecraft's transfer to geostationary orbit on 29 August using the new restartable bipropellant Liquid Apogee Propulsion Subsystem (LAPS), the engine developed less than 10 per cent of its rated thrust. Three subsequent attempts to carry out the transfer on 31 August were unsuccessful, and on 1 September controllers separated the propulsion system from the spacecraft, leaving it stranded in an 8,000 x 39,000 km elliptical orbit. KIKU-6's 660 kg payload included eight antenna systems which were to have explored both satellite-to-satellite communication and links to fixed and mobile satellite communications systems at frequencies in the optical laser band, S-band, K-band, and O-band. The satellite was also to have tested innovative designs for carbon-fibre-reinforced satellite bus structures, nickel-hydrogen batteries, electrostatic (ion) stationkeeping propulsion, and a three-axis attitude stabilization system, as well as the failed LAPS. NASDA had expected to conduct those tests which were still feasible with the spacecraft in its elliptical orbit, but degradation of its solar panels due to repeated passage through the Van Allen radiation belts reduced the spacecraft's power from 5.8 kW to 4.7 kW during September, with a projected decay to 2 kW by early 1995. No experiments can be conducted at power levels below 2 kW.

The next satellite in the series, the Communications and Broadcasting Engineering Test Satellite (COMETS), was shipped from the manufacturer (NEC Corporation) to NASDA on 21 June for 18 months of tests. The $400 million, 1,800 kg COMETS spacecraft, to be launched aboard H-2 in January 1997, will verify many of the new technologies planned to be tested on KIKA-6 and will also carry a 5.5-kW gallium arsenide solar array. Its primary mission will be to evaluate operations in the Ka-band, including direct broadcasting, intersatellite communications, and transmissions to mobile ground stations.

On 19 November 1993, Mexico's Solidaridad-1 communication satellite, the first of two second-generation spacecraft that replace the two current Morelos satellites orbited in 1985, was launched aboard an Ariane 44LP, along with a European weather satellite Meteosat-6. The two Hughes-built HS-601 Solidaridad spacecraft will expand the Morelos HS-376 constellation's capacity by 50 per cent in C-band and 150 per cent in Ku-band, and will add L-band (mobile communications) capability. Solidaridad's Spanish-language coverage includes all of Central and South America and parts of the southwestern and southeastern United States.

Magyarsat Satellite Telecommunications Ltd. was established in December 1993 to provide television and radio broadcasting services as well as voice and data transmission in Hungary and neighbouring countries. Key participants are Antenna Hungaria and Israel Aircraft Industries (IAI). The system will use IAI's 970 kg AMOS geostationary orbit satellite, which is equipped with seven Ku-band transponders. It is scheduled to be launched as a secondary payload aboard an Ariane launcher in mid-1995. Major subcontractors to IAI are Dornier (Germany), DASA (Germany), and Alcatel Espace (France).

On 8 December 1993, Indonesia's Media Citra Inc. signed a $100 million contract with the United States firm CTA Inc. for a lightweight (1,040 kg) television/radio broadcast satellite, Indostar-1, to be launched in early 1996. The first of four planned spacecraft, Indostar-1 has thee television and two radio transponders and a planned seven year lifetime. Receivers will use a 1-m dish antenna costing between $100 and $450. Besides entertainment and news, the Indostar spacecraft will deliver educational and training programmes, telemedicine, and weather forecasts direct to Indonesian homes.

Thaicom-1, owned and operated by Bangkok's Shinawatra Group, was also launched by Ariane on 17 December 1993 to provide regional direct-broadcast television, business network communications, and other communications services to Laos, Cambodia, Vietnam, and Myanmar. A second Hughes-built satellite, Thaicom-2, was launched on 7 October, and a third is expected to be contracted for and launched around mid-1995. The spacecraft each carry 10 C-band and two Ku-band transponders. Ground receivers for the planned 30 channels of direct-broadcast service will require 60 cm antennas that will initially cost about $800 each. It is expected that the cost will eventually drop to as low as $300.

Rimsat Ltd.'s third Russian Gorizont satellite was launched to its orbital position over the Asia Pacific region from Baikonur Cosmodrome on 20 May aboard a Russian Proton, joining a Gorizont launched in November and one moved to the Asian region in July 1993.

Hong Kong's APT Satellite Company launched its first spacecraft, Apstar-1, on 21 July aboard a Chinese Long March 3A rocket and a second spacecraft was scheduled to be launched by the end of 1994. All of the HS376 Apstar-1's 24 C-band transponders have been sold; Apstar-2's 26 C-band and eight Ku-band transponders are expected to be fully committed before launch. Key customers include the Turner Broadcasting System, Time-Warner, ESPN International, Discovery Communications, and Viacom International, all of the United States, and Hong Kong's Chinese language TVB International. APT had planned to place Apstar-1 in a geostationary orbit slot at 131 degrees east, but because its signals could then interfere with Rimsat-1, in a Tonga slot, and with Japan's CS-3A, each of which is only one degree away from the intended Apstar-1 slot (the ITU separation guideline is 2 degrees), APT on 5 September agreed to move its satellite to a slot at 138 degrees east, leased from Tonga.

Malaysia's first satellite communications network, the $380 million Malaysian East Asia Satellite (Measat) system, was announced on May 17th. Binariang SDN BHD contracted with Hughes on that date to build and launch Measat-1 in December 1995, with an option for a second spacecraft. On 7 July Binariang SDN BHD contracted for an Ariane launch of Measat-1. The 1,400 kg HS376 satellite, which features gallium arsenide solar panels (see below) and shaped antennas for tight signal focus, will carry 12 C-band and 4 Ku-band transponders to deliver 32 digitally compressed television channels to customers' antennas as small as 50 cm in diametre. The United States government is providing an additional $400,000 grant to train Malaysian workers in satellite technology and management.

2. Mobile Communication Systems

A study released by KPMG Peat Marwick (United Kingdom) on 23 March estimated that the annual market for satellite-delivered mobile telephone services will climb from its present level of less than $1 billion to $11-22 billion by the end of the decade. The report stated that such a market will support only two or three satellite constellations worldwide. Because most heavily industrialized regions are well served by ground-based cellular systems, much of the future market growth for satellite-delivered services will be in rural or undeveloped areas, primarily in Australia, Brazil, Canada, China, India, Indonesia, Malaysia, Mexico, Pakistan, Poland, Russia, South Africa, South Korea, and the United States

During its 28 February - 3 March meeting, Inmarsat's council rejected the proposed Inmarsat-P global hand-held satellite telephone system because of concerns about technology readiness, profitability, and timing of the 12-satellite, $2.6 billion system. However, on 13 May the Inmarsat Council approved the creation of an affiliated private-sector corporation to set up and operate the system, and on 9 September the Council approved a plan to solicit the first $1 billion capital investment from the organization's 75 members. The new entity is expected to be organized by January 1995 and to take over the Inmarsat-P system management early in 1995.

On 5 January, American Mobile Satellite Corporation (AMSC) announced completion of its required financing of $602 million, via a public stock offering which brought in $236 million. AMSC will launch its first Hughes-built satellite late this year, and by May 1995 expects to begin serving customers in remote areas not accessible to cellular telephones. The two satellite AMSC system will have a capacity of 340,000-677,000 users, which represents 3-5 per cent of the present United States cellular telephone market.

After years of uncertainty and controversy, the United States Federal Communications Commission (FCC) on 14 October finally issued licensing rules for mobile telephone systems using low Earth orbit satellites, generally called "big-LEO" systems, clearing the way for spectrum allocations and licenses to be issued in January 1995. The five competing applicants are Iridium (projected cost: $3.4 billion, 66 satellite constellations), Globalstar ($1.8 billion, 48 satellites), Odyssey ($1.3 billion, 12 satellites), Ellipso ($1 billion, 14-18 satellites), and Aries (48 satellites).

On 20 October, the FCC issued the first operating license for a low Earth orbit constellation to Orbital Communications Corp. (Orbcomm). The 36 satellite two-way messaging system, a so-called "Little-LEO" system, will provide paging, data transfer, and position-location services via hand-held terminals, first in the United States and eventually worldwide. The first two satellites will be launched in late 1995 or early 1996 on

Pegasus rockets. Orbcomm has sufficient financing in place for the first 26 satellites via a joint venture with Canada's Teleglobe, Inc. The total cost of the system is estimated at $146 million.

On 24 March, Loral Corporation (United States) announced achievement of its first financing goal for the Globalstar system: $275 million invested by eight companies toward the total system cost of $1.8 billion. The eight investors, all of whom have key roles in system design, development, construction, operations, and marketing, are Loral (United States), Alcatel Espace (France), Qualcomm (United States), Alenia Spazio (Italy), AirTouch Communications (United States), Deutsche Aerospace (Germany), Dacom Corporation and Hyundai Electronics (South Korea), and Vodafone Group International (United Kingdom). Loral expects to obtain another $300 million via a public stock offering, $865 million through bank loans, $200 million from companies selling Globalstar products, and $160 million from franchise fees. Service is planned to start in 1998, using 48 400 kg satellites plus eight on-orbit spares in low Earth orbit. Each satellite will carry 16 spot-beam antennas. Globalstar will offer telephone, fax, and position location services to hand-held terminals costing less than $500, with per-minute use charges of about $0.65.

Iridium, Inc., which had achieved its first-phase financing goal in 1993, announced in September completion of full equity financing ($1.57 billion) for its 66-spacecraft system. The balance of the $3.4 billion venture will be funded by debt financing. New investors include Germany's Vedacom, Korea Mobile Telecommunications Corporation, and a South American consortium named Iridium Sudamerica. Iridium also announced plans for the first commercial space use of a military technology, Microwave and Millimeter-wave Monolithic Integrated Circuits (MIMICs). Each Iridium spacecraft will be equipped with over 1,600 gallium arsenide MIMIC chips for intersatellite communication functions.

A license application was submitted to the United States FCC on 21 March by Teledesic Corporation, formerly Calling Communications, for its $9 billion 840 satellite system. The proposed global network would be entirely independent of all other communications networks, both satellite and ground-based, and would provide high-quality video, data, and voice communications between ground stations equipped with Ka-band antennas from 16 cm to 1.6 m in diametre. Initial investors in the system, all from the United States, include McCaw Cellular Communications, Craig McCaw (its chairman), William Gates (chairman of Microsoft Corporation), and Kinship Partners II.

In April, the United States Department of Transportation's Office of Commercial Space Transportation concluded that only two or three of the dozen proposed low Earth orbit communications systems would ever reach their operational phase. The United States FCC plans to award licenses to United States operators, who constitute the majority of global system proposals, in January 1995. Current proposals include are shown in the following chart:

System	Company	Satellites	Mass(kg)	Launch
Aries	Constellation Communications (U.S.)	48	180 kg	1995
Elekon	ESD (Germany) & NPO-PM (Russia)	7	*	1995
Ellipso	Ellipsat Int'l (U.S.)	14-18	175	1996
Globalstar	Loral Qualcomm Sat. Svcs. (U.S.)	48	380	1997
Iridium	Iridium, Inc. (U.S.)	66	680	1996
LEO One	LEO One Panamericana (Mexico)	12-36	160	1995
Odyssey	TRW, Inc (U.S.)	12	1140	1997
Orbcomm	Orbital Communications (U.S.)	36	40	1994
Signal	Russia	48	680	?
Starnet	Starsys Global Positioning Inc. (U.S.)	24	?	1996
Taos	CNES (France)	12	150	1995
Teledesic	Teledesic Corp (U.S.)	840	780	1999
Vitasat	VITA, Surrey Satellite (UK)	2	45	1995

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*Secondary payloads on Cosmos spacecraft

Canada's TMI Communications signed an agreement on 23 March with Telecommunicaciones de Mexico for testing the ground-based portion of its network before launching the Canadian MSAT in April 1995. Contracts were also signed on 12 January with Westinghouse and Mitsubishi, and on 9 March with Narrowband Telecommunications Research, for manufacturing and distributing MSAT ground communicators.

Telebras of Brazil announced on 16 March its plans to build and launch Brazil's own low orbit mobile satellite communication system, called Eco-8. The system will consist of eight small satellites orbiting at 1,900 km altitude, will cost an estimated $265 million, and will provide cellular telephone linkages as well as fax, direct communications, and position location services. Test spacecraft are to be built by Brazil's National Institute of Space Research (INPE).

On 5 August, Hughes Communications Inc. (United States), Singapore Telecommunications Ltd., Singapore Technology Ventures, and PT Pasifik Satelit Nusantara (Indonesia) signed an agreement to explore a next-generation mobile communication system for hand-held telephones using a geostationary satellite instead of a low-altitude constellation. The Asia Mobile Telecommunications project would service most of Asia from a single high-power geostationary-orbit satellite using tightly focused spot beams to provide adequate power for hand-held telephones, and frequency reuse to permit as many as one million telephones to use the satellite. The system, including a ground spare satellite, is estimated to cost about $900 million. Its developers claim that this system will have lower per-minute costs than other systems based on the use of geostationary satellites.

3. Navigation and Position Location

The final United States Global Positioning System (GPS) spacecraft was successfully launched into orbit by a Delta-2 rocket on 9 March, completing the constellation of 24 spacecraft. Three of the orbiting satellites are spares; four more ground spares are available when orbiting spacecraft fail. On 17 October, the United States Federal Aviation Agency (FAA) administrator promised the International Civil Aviation Organization (ICAO) that the United States will provide free use of the system for at least 10 years. GPS and Russia's Global Navigation Satellite System (GLONASS) are candidates for the Global Navigation Satellite System (GNSS) projected by ICAO for use by all of the world's airlines. GLONASS, meanwhile, moved closer to operational status with the launch of three satellites into a 64.8-degree orbital plane on 11 August by a Proton rocket. These satellites joined 13 other GLONASS spacecraft in two other orbital planes. Three more satellites were scheduled for launch by the end of 1994, with nine more to be orbited, three at a time, during 1995, to complete the constellation of 24 operational satellites.

The United States FAA announced on 8 June that it was canceling its ground-based navigation system plan, including the Microwave Landing System (MLS) network, in favour of one based on the use of GPS satellites. The new plan includes a $500 million network of ground stations to provide the differentially corrected GPS signals that enable pilots to locate their aircraft within a few metres. Receivers for commercial transport aircraft are expected to cost $20,000-$50,000; less complex instruments for general aviation will cost only $1,000-$5,000. Airline tests of GPS navigation, including control of Category 2 and Category 3 landings, continued actively in 1994 to demonstrate their viability to an ICAO meeting scheduled for March 1995. Demonstrations of in-flight navigation and all categories of landings were conducted by American Airlines, United Airlines, Continental Airlines, United Parcel Service, and a host of equipment manufacturers in a wide range of transport aircraft.

On 11 August, Rockwell International (United States) announced a joint programme with the Russian State Research Institute of Aviation Systems (GosNIIAS) to coordinate navigational signals from the United States GPS and the Russian GLONASS so that commercial aircraft worldwide can use signals from both systems interchangeably to pinpoint their locations within 100 m in three dimensions. Plans include a new ground station at either Khabarovsk or Vladivostok to receive signals from aircraft. By providing navigational capability over all of Russian territory, the new system, which is scheduled to be operational by late 1995 or early 1996, will cut travel time between the United States and the Far East (especially China and Japan) significantly. Rockwell is also working with Hughes and GosNIIAS to provide business training, technology, and other products for the Russian air traffic management system. Products will include a GPS receiver and a Traffic-alert Collision Avoidance System (TCAS) manufactured by Rockwell, and Hughes' TracView air traffic controller's work station.

A United States company, Magellan Systems Corporation, signed a five-year, $100 million agreement in November 1993 with three Japanese companies representing Toyota, Toshiba, Hitachi, and Nissan for development and delivery of GPS navigation ground stations to be integrated in Japanese automobiles. In the United States, a number of programmes were initiated in 1994 to evaluate the use of GPS navigation systems in automobiles. The regional telephone company NYNEX began testing its Northstar system in January with 140 New York area automobiles, expanding the test to include 30 rental cars in April. The Northstar system, which connects the GPS signals to cellular telephones, provides drivers with emergency assistance, directions to nearby businesses, and theft protection as well as navigation services. Similar services are provided by a $2,000 GPS option on General Motors Oldsmobiles using dashboard displays. This option has been available since August. A third company, Travtek, is testing driver reactions to navigation and other advanced systems similar to Northstar's on 100 rental cars in Orlando, Florida. In September, one rental car company began equipping all its rental cars in southern Florida with Guidestar, a computer-programmed guidance system using GPS in conjunction with car-mounted sensors. The Guidestar system, developed by Zexel USE and built by Rockwell International, has a small video screen that shows the driver the car's position relative to destinations selected from among thousands of business, hotels, restaurants, banks, hospitals, and tourist attractions.

In November 1993, a United States company, Differential Corrections, announced plans to extend its eight-city United States operations to provide extremely accurate position location and navigation worldwide. The company's ground-based receivers use GPS signals differentially corrected by signals broadcast from local frequency-modulated (FM) radio stations. For $75 per year, subscribers receive position determination signals accurate to within 5-10 m; $125 per year brings position accuracy to 2-5 m; and $600 per year buys 1 m accuracy. Similar services are provided in the United States by a company named ACC-Q-POINT.

On 13 March, the United States Air Force launched a Taurus rocket carrying a $56 million 12-month experiment, Technology for Autonomous Operational Survivability (TAOS), which initiated tests of a unique navigation system that uses only the Sun, Earth, and Moon to locate its position within about 100 m. Because it requires no assistance from ground tracking stations, such a system, if successfully demonstrated, could sharply reduce the cost of operational satellites. Although the spacecraft suffered a disabling power loss on 19 July due to failure of its attitude control system, a new software package loaded into TAOS restored it to full capability in early October.

The first of five 55 kg German Safir two-way messaging and position-location satellites was launched in May from Plesetsk as a secondary payload aboard a Russian Resurs spacecraft. The OHB System spacecraft communicates with users via small ground terminals.

Russia issued an operating license on 10 June for Elekon, a seven-satellite two-way messaging and position-location system aimed primarily at cargo monitoring on trucks and ships. The system, a joint venture between Elbe Space and Technology Dresden GmbH (ESD), Germany, and the Mercury affiliate of NPO Prikladnoi Mekhanki (NPO-PM), Russia, which will build the spacecraft, is expected to be launched between June and October 1995 as auxiliary payloads aboard Kosmos satellites lifted by Zenit rockets from Baikonur Cosmodrome. All seven satellites will be in 1,150 km near-polar orbits (83 to 90 degrees) for northern latitude coverage.

On 12 October, China announced development of Twin-Star, a navigation satellite system consisting of two geostationary orbit satellites 40 degrees apart that would provide China and other Asian countries with position-location accuracy of 20 m. Launch is planned for 1998.

B. Remote Sensing

1. Earth Observations

Detailed analyses of the damage caused by extensive 1993 forest fires in California were conducted by an industry task force using SPOT satellite images to catalogue specific damage features (by comparing them with pre-fire images), in conjunction with GPS signals to map the locations of structures destroyed by the fires. The programme, first conducted in Laguna Beach and Orange County, was later extended to other fire-damaged areas. Data from the Advanced Very High Resolution Radiometers (AVHRR) aboard the United States NOAA polar-orbit satellites were also used to monitor the greenness and dryness of land cover for the United States Forest Service to help pinpoint the high-risk areas most susceptible to future fires.

Results of a detailed NASA study measuring deforestation rates using satellite imagery are expected to revise the environmental history of tropical forest areas in South America, Africa, and Asia. Data released in March suggest that Brazilian forests are being destroyed at a rate of 15,000 square km per year, compared with previous estimates (based on extrapolations from limited sample ground surveys) of 45,000 square km per year.

In May, data from the Spaceborne Imaging Radar C and X-band Synthetic Aperture Radar, carried aboard United States Shuttle Endeavour in April (see below), were used by Rutgers University's Center for Remote Sensing and Radar Analysis (United States) in combination with previous ground-based information from GPS receivers to map the homeland of the over 600 mountain gorillas who live in the Virunga Volcano chain of mountains in Rwanda, Zaire, and Uganda. The three-dimensional charts of this region, much of which has never been mapped and is now virtually inaccessible from the ground or from the air due to local conflicts, will be used by the Dian Fossey Gorilla Fund to help understand the gorillas' movements and habitation preferences in the mountain chain.

The Atlantic Centre for Remote Sensing of the Oceans (Canada) submitted a proposal to ESA in June to study salmon habitats using a radiometer aboard ESA's ERS-1 satellite, launched in 1991. Data from the satellite's Along Track Scanning Radiometer (ATSR) will be used in conjunction with data from the AVHRRs aboard United States NOAA polar-orbit weather satellites to measure ocean surface temperatures and determine the regions suitable for salmon. The salmon are found in regions where the water surface temperature is between 4 and 12 degrees Celsius, but they prefer 6-8 degrees. ATSR data are particularly useful because the instrument can measure water surface temperatures in the presence of cloud cover.

On 8 July, the mammal research programme at Oregon State University (United States) launched a summer programme to study the speech habits of blue whales. The programme used Argos communications devices aboard two polar-orbit NOAA weather satellites to receive transmissions from ten whales which had been tagged with small recorders. The recorders monitored the whales' dives and speech periods and transmitted their data, which include the whales' locations as well as their speech and dive information, to the satellites when the whales surfaced to breathe. The Argos system was developed by France, and is operated by the French company COS/Service Argos. The United States Office of Naval Research provided funds for the transmitters, which cost about $5,000 each, and project operations, estimated at about $10 per day per whale.

In July, a cooperative pilot project was initiated using the ESA Marecs-A satellite to transmit radiation-level and location data from trucks in the Ukraine carrying nuclear waste to a central control centre. The project is funded jointly by ESA, Fair SpA (Italy), which manufactured and installed ESA's Prodat-2 mobile satellite terminals in the trucks, the Ukraine National Space Agency, the Ministry for Chernobyl (Ukraine), and the Kiev Institute of High Technology (Ukraine).

Canada's new Long Term Space Plan, issued on 3 June, included $175 million for a follow-on to Radarsat-1, currently scheduled for launch in March 1995. Radarsat-2 would be launched in 2000. The Canadian Space Agency (CSA) plan specifies a total of $552 million for observation (including Radarsat-2), $237 million for communications (including $136 million for advanced technology and an international mobile communications system), $262 million for space technology, and $223 million for space science. The CSA plan includes the expectation that private sector funds will supplement the government budget in those areas having commercial potential.

On 1 November 1993, three United States companies, Orbital Sciences, Itek Optical Systems, and GDE Systems, created a new firm, Eyeglass, to collect and sell satellite images having 1 m resolution. Itek will build the sensors, GDE will perform ground processing, and Orbital Sciences will build the SeaStar-class satellite bus and launch it on a Taurus or Pegasus rocket. Most of the company's financing was provided by Saudi Arabia's Eirad Company, Ltd., which plans to distribute imagery in the Middle East through a new subsidiary, Eyeglass Saudi Arabia, provided national security concerns expressed in October by some members of the United States Congress can be allayed. Eyeglass plans to develop and fly its initial satellite by 1996 at a cost of $150 million, about 25 per cent of competitive 1 m resolution systems planned by Lockheed and Worldview Imaging.

The concept moved closer to realization on 10 March, when United States President Clinton approved the commercial marketing of high-resolution spacecraft imagery. Lockheed's commercial high-resolution system subsequently secured its license from the United States Department of Commerce on 22 April under the new policy, and Lockheed subsequently created a new company, called Space Imaging, Inc., to market the 1 m resolution images produced by the satellite system.

Another high-resolution venture started in November 1993, when the United Kingdom's JEBCO Information Services Ltd. announced the marketing of Russian Resurs satellite images with 3 m, 5-8 m, and 20 m resolution by a new subsidiary, WorldMap International. The target market is mapmakers who want sharper images than those provided by SPOT or Landsat. Raw analog image data are converted to digital images in Moscow by a Russian firm, Priroda, using JEBCO-supplied computer equipment. Images are available from the entire Earth between 82.3 degrees north and 82.3 degrees south latitudes, at prices ranging from $,1325 for a 20 m resolution image to $10 per square km for 3 m images. On 26 September, WorldMap announced that direct digital image data from Russian military reconnaissance satellites would be offered on a continuous basis, unlike the Resurs data, which are delivered via recovery capsules. The 3 m resolution digital image data are expected to be the first of their kind on the world market. They will be available on an operational basis in early 1997.

A United States company, Autometric Inc., also announced in March its plans to market 2 m resolution images from Russia's KVR-1000 satellite camera and 6 m resolution images from the Russian MK-4 multispectral camera, as well as images from the KFA-1000 color infrared camera, the TK-350 topographic mapping camera, and the Almaz satellite's radar imager.

On 8 June, NASA awarded contracts to develop and build two small Earth observing satellites, Lewis and Clark, within two years. Lewis, to be built by TRW Space and Electronics Group under a $59 million contract, will have 384 spectral bands compared with Landsat's 10, enabling it to distinguish different species of trees and plants. Its four instruments will have applications in agriculture, Earth science, environmental assessment, forestry, land management, and industrial planning. Clark is to built by CTA Inc. for $49 million; its four instruments and 3 m resolution capability are designed to provide planning, disaster management, and commercial development information. Each spacecraft will weigh about 275 kg, about 70 per cent of which is expected to consist of payload, as compared with current satellites' 40 per cent. They will be launched by Pegasus XL rockets.

Europe's second large radar-equipped Earth remote sensing satellite, ERS-2, was assembled in April at the European Space Research and Technology Centre in Noordwijk, Netherlands. The 2.5-tonne spacecraft, expected to be launched aboard an Ariane launcher in 1995, is nearly identical to its predecessor, ERS-1, except for the addition of an ozone measurement instrument.

2. Atmosphere and Ocean Observations

On 10 May, United States President Bill Clinton approved a plan to combine the nation's civil and military weather satellite systems, and proposed that the United States and Europe build a new joint polar-orbit system to serve both civil and military users. Eumetsat agreed to the proposal at its council meeting in June. The new system would consist of two United States polar-orbiting spacecraft (reduced from the current four -- two civil and two military) and one European satellite carrying United States instruments, plus a spare. Eumetsat's Metop polar-orbit satellite series, planned for launches in 2000 and 2005, will not be included in the new system, the first of whose spacecraft is not expected to fly until 2006. The United States plan also includes transfer of Landsat-7 procurement from the DOD to NASA. The Landsat-7 ground system will be supported in part by the United States NOAA, which also oversees operations of the existing Landsat-4 and -5 spacecraft.

NASA's Total Ozone Mapping Spectrometer which is being flown aboard the Russian Federation's Meteor-3 spacecraft, was reactivated after an apparent June 1993 failure. On 6 October 1993, its observations confirmed ground-based measurements of record low ozone levels over the Antarctic: total destruction of ozone between 13.5 and 19 km altitude. Findings from the 18 kg United States Polar Ozone and Aerosol Measurement (POAM) payload, launched aboard the French SPOT-3 satellite in September 1993, were announced at the American Geophysical Union meeting in May 1994. Data from seven of POAM's nine sensors, each tuned to a different solar radiation frequency, showed remarkable correlation between the Antarctic ozone hole and the polar vortex.

The United States Geostationary Operational Environmental Satellite (GOES-8) reached its final orbit on 27 April after several anomalies occurred following its successful 13 April launch. Its first test image was transmitted to Earth on 9 May, and the satellite became fully operational in October.

Development of NASA's $8 billion, 17-satellite Earth Observing System (EOS) continued toward its initial launch date in 1998 despite two reports critical of key programme features. The first of these was released on 27 December 1993 by the United States Congress Office of Technology Assessment. It stated that the overall United States global change programme, of which EOS comprises about 80 per cent, was "fragmented, inflexible, and off-target," and did not address urgent environmental phenomena such as biodiversity, ozone depletion, population growth, and forest distribution. The study criticized EOS's overreliance on large satellites and the programme's insufficient emphasis on aircraft, balloons, and smaller spacecraft. The second study, released by the National Research Council on 15 January, concluded that NASA's management of the EOS Data Information System (EOSDIS) was overly bureaucratic, inflexible, did not allow for use of commercial information systems, and has a high risk of failure. NASA has already begun to implement the changes recommended by the study.

NASA was also forced to reorient its EOS programme plan for the third time in four years when the United States administration in mid-year cut another $750 million from the programme budget through 2000. The new EOS plan, announced on 6 September, extends the launch interval between spacecraft from five years to six years, places several EOS payloads aboard non-EOS spacecraft (including several from other nations), slows the data-processing rate, and defers some hardware purchases until after 2000. The first AM spacecraft in the series, which will cross the equator in the morning to study clouds, aerosols, and soils, is scheduled for launch in June 1998; the first PM spacecraft, crossing the equator in the afternoon and analyzing precipitation, snow and ice cover, and air temperatures, will be launched in December 2000, and the first Chemistry satellite, designed to create chemical profiles of the atmosphere, is scheduled for launch in 2002. The most recent budget cut eliminated the radar and laser altimetry payloads originally planned to measure wave heights, ocean currents, and ice sheets. NASA hopes to get these data from a proposed United States Navy Geosat follow-on spacecraft or a successor to the Topex-Poseidon satellite, in collaboration with France.

The Los Alamos and Sandia National Laboratories (United States) began construction this fall of a satellite designed to provide accurate detection and monitoring of atmospheric discharges, including nuclear explosions. The satellite, named Fast On-Orbit Recording of Transient Events (FORTE), combines optical and electromagnetic sensors, rather than the solely optical sensors used on previous discharge-detecting spacecraft, allowing it to "see" through clouds. It builds on prior experiments with electromagnetic sensors flown on the ALEXIS satellite last year.

On 26 October, a Proton rocket launched Russia's first geostationary orbit meteorological satellite, the 2,580 kg Elektro, from Baikonur Cosmodrome. Elektro will provide atmosphere images having 1.25 km resolution in the visible spectrum and 6.5 km resolution in the infrared spectrum. It will also collect and disseminate Earth surface data taken by sea-based, ice-based, and shipborne platforms. Elektro has a design lifetime of two years.

On 1 August, NASA and Brazil announced a series of 33 sounding rocket flights to take place from mid-August to mid-October to study turbulence in the ionosphere from 100 to 1,000 km above the magnetic equator. The Brazilian launch site at Alcantara, only 1 degree away from the magnetic equator, is an ideal launch location.

C. Commercial Developments

In November 1993, NASA opened Technology Commercialization Centers at its Ames Research Center in California and at Johnson Space Center in Texas. The new centres negotiate licensing agreements with commercial firms to utilize NASA-developed technology, and identify those NASA technologies that can serve as the basis for the establishment of new companies. The centres are being organized under a NASA contract by the IC-Square Institute of Austin, Texas, which has been successfully commercializing technology since 1989.

On 16 December 1993, however, NASA notified six of its Centers for Commercial Development of Space (CCDSs) that their support would be terminated at the end of 1993. The order shut down the Center for Commercial Crystal Growth in Space at Potsdam, NY; the Center for Advanced Materials in Columbus, OH; the Center for Materials and Space Structures in Cleveland, OH; the Center for Cell Research in University Park, PA; the Center for Space Transportation and Applied Research in Tullahoma, TN; and the Space Automation and Robotics Center in Ann Arbor, MI.

During late fall 1993 and early 1994, the United States Technology Reinvestment Project, managed by the Advanced Research Projects Agency (ARPA), initiated a number of shared-cost programmes aimed at spurring the development of technologies having commercial potential. Those with space orientation include commercializing broadband digital communications (Raytheon Company); development of a new lightweight K-band satellite antenna that quintuples antenna power and halves its weight (Space Systems/Loral); development of rechargeable lithium batteries for spacecraft (Lockheed); development of a 1.1-MN thrust hybrid rocket booster (American Rocket Company; see details below); and using GPS satellite signals and laser guidance for mining, highway construction, and dam-building (Magnavox and Caterpillar Tractor).

On 22 December 1993, Martin Marietta announced plans to purchase the General Dynamics Space Systems Division (GDSSD) for $208.5 million. The acquisition was completed on 2 May; the former GDSSD is now the Martin Marietta Astronautics Space Systems Division. The first launch conducted by the new organization was the abovementioned United States Navy UHF-3 satellite in June. There are plans in place to consolidate the Atlas Centaur production line in Denver with that of the Titan vehicles; that move is expected to be completed in early 1996. Launch operations at Cape Canaveral Air Force Station (CCAFS) and VAFB will also be consolidated, with October 1995 the target date for completion. Martin Marietta and Lockheed subsequently (on 29 August) announced plans to merge in 1995, a move that will create the world's largest aerospace company with annual gross revenues of $23.5 billion.

On 30 June, GE American Communications Inc. (United States) announced the acquisition of GTE Spacenet Corporation (United States). Adding GTE's eight commercial communication satellites to GE Americom's seven, makes the new company the largest United States commercial satellite owner (Hughes Communications owns 11).

Space Systems/Loral (United States) and Deutsche Aerospace (Germany) announced on 31 March their plans to construct a plant in Palo Alto, California (United States) to develop, build, and market space microgravity laboratories for both government and commercial customers. The laboratories could be designed to fly on the Space Shuttle, the space station, or robot spacecraft, and will incorporate furnaces, optical systems, incubators, life-support systems, and other experimental facilities.

Matra Marconi Space (France) purchased British Aerospace Space Systems on 19 July for $84 million. The new company's expected annual revenues of $1.2 billion make it the world's third largest manufacturer of civil satellites.

On 11 August, Orbital Sciences Corporation (United States) purchased the Fairchild Space and Defense Corporation (United States) from Matra Hachette Group (France) for about $80 million, placing the company in an excellent position to dominate the growing small-satellite market (500-2,000 kg).

On 8 July, the China Aerospace Corporation and Germany's Deutsche Aerospace established an equal-share joint venture called EurasSpace to develop and build commercial communications and Earth observation satellites. The new company's first product, a communications satellite (Sinosat) for the Chinese Sino-Satellite Communications Company, Ltd., is a commercial follow-on to the Chinese DFH-3. The company will also offer satellite operations services. It has been estimated that China will need 20-30 communications satellites carrying 500-600 transponders during the next 10-12 years.

On 8 April, the Alaska Aerospace Development Corporation (United States), formed in 1991, announced plans to build a commercial launch site on Kodiak Island, Alaska, for less than $15 million in less than two years. Initial plans for the polar-launch facility call for one pad with the capability to accommodate rockets up to the size of a Thiokol Castor 120, but future expansion to four pads is expected. The Kodiak Island site plan replaces the original Poker Flats launch complex concept, which the company said was flawed by inhabited land overflight considerations.

Euroconsult's annual "World Space Markets Survey: 10-Year Outlook," published in mid-July, projected annual sales of satellite ground-terminal equipment, not including the burgeoning sales of GPS and hand-held telephone receivers, to grow from $3.4 billion in 1993 to about $5 billion in 1995, creating a 12-year total market (1992-2004) of $65 billion to $83 billion, depending on the commercial success of direct-broadcast services (see above). Up to $17.4 billion in commercial spacecraft sales and $12.9 billion in launch revenues are also projected for the same 12-year period.

Another study, released in July by DFI International (United States), "The Small

Satellite Market: Opportunities and Strategies," predicted that the market share of small satellites (defined as weighing less than 1,500 kg) will increase from its present 5 per cent to 11 per cent by 2000. Total smallsat revenues in 2000 are expected to be $3.6 billion, of a total space market that year of $33.2 billion.

IV. MANNED EARTH ORBITAL ACTIVITIES

A. Space Station Development

Planning for United States-Russian Federation interaction on the international space station programme dominated manned Earth orbital activities this year. A bilateral accord signed by NASA Administrator Daniel Goldin and RSA Director-General Yuri Koptev on 3 November 1993 called for 10 dockings of the United States Shuttle at the Russian Mir Space Station between 1995 and 1997, but NASA subsequently (in August) reduced the firm number of Mir missions to seven, with three additional missions as an option. The plan canceled four Spacelab missions originally scheduled during those years. It also included modifications to Space Shuttle Columbia (in addition to Atlantis) to enable it to dock with Mir in case the three additional missions are needed (Atlantis alone can handle the seven firm missions). Design and construction of the necessary docking mechanism began in 1993, via a NASA contract with Rockwell International (United States). Rockwell is obtaining the necessary hardware from NPO Energiya (Russia). Target dates for the seven missions are June 1995, October 1995, March 1996, July 1996, December 1996, May 1997, and September 1997.

Details of the Russian-United States accord were contained in a contract signed on 23 June. It called for the United States to pay Russia $305 million to help upgrade the Mir station during the next three years, and $95 million toward Russian elements of the international space station to be launched beginning in 1997. Projects covered by the $95 million segment include early work on the Russian FGB tug, which will provide guidance, navigation, and control for the station (the tug itself is to be built by Khrunichev Enterprise under a separate $300-million contract with Lockheed); scientific experiments aboard Mir; Russian work on a solar-thermal dynamic power system that could ultimately replace the photovoltaic panels of the current station design; and early work on a docking system for the station, to be tested aboard Mir. Although not covered by the 23 June contract, United States Vice President Al Gore and Russian Prime Minister Viktor Chernomyrdin also discussed proposals to study a Mars Together programme for 1998-2001, and the Fire and Ice proposal for joint missions to the Sun and to Pluto.

A former White House advisory panel reviewed the radically revised space station programme on 25-26 March, and concluded that great progress had been made toward the new configuration, especially in revamping the former unwieldy management and programme organization. The revised plan incorporates both an annual $2.1 billion budget cap and the abovementioned close cooperation between the United States and the

Russian Federation as well as with ESA, Canada, and Japan.

Further definition of the space station assembly and configuration planning continued throughout 1994. On 28 September, NASA identified the assembly sequence as requiring 44 launches from November 1997 through station completion in June 2002: 19 Shuttle flights for assembly, five for utilization, two to deliver and outfit the Japan Experiment Module, 14 Russian flights, and two Ariane-5 flights to deliver and outfit ESA's Columbus Attached Payload Module. The plan includes launching a controversial 11,000 kg centrifuge for life science experiments in October 2001 and launch of the Russian solar power platform in November 1998 and February 1999, reversing a July decision to delay that element until 2000.

On 23 February, two United States astronauts, Norman Thagard and backup Bonnie Dunbar, began training in Star City, near Moscow, for a three-month mission aboard the Mir Space Station scheduled to begin on 14 March 1995. Thagard will be the first American to be launched by a Russian rocket. The 19-tonne Spektr module, scheduled to be launched in May, will carry equipment to be used by Thagard for experiments aboard Mir. He will return to Earth with two Russian crewmates aboard United States Shuttle Atlantis in mid-June, after the first of the abovementioned Shuttle-Mir docking missions. On 19 October, a joint simulation of the docking maneuver between Shuttle Atlantis and Mir was conducted successfully by a United States team in Houston and a Russian team in Kaliningrad.

ESA's ruling council decided on 16 January to merge the Columbus space station laboratory and the Manned Space Transportation programmes at the end of March, reconciling a previous deadlock between France and Germany. Total two-year funding for the new joint programme was set at $554 million. ESA ministers will in 1995 decide whether or not to proceed with hardware development, estimated to cost a total of $4.7-5.2 billion for the Columbus laboratory and an Apollo-type crew transport capsule.

On 15 September, ESA also agreed to develop a European Robotic Arm (ERA) for use on the Russian Federation's portion of the international space station, at a projected cost of $180 million. The 10 m long ERA will be a typical multi-body system with flexible joints and links, equipped with its own computer to enable operation in a variety of automatic and semi-automatic modes. The seven-jointed system will be able to "walk," and will be conveyed along the space station on a trolley. It can be operated remotely by an astronaut inside or outside the station.

On 25 January, China's National Space Administration announced plans to build a two-person capsule to be launched by 2000. Based on preliminary work started in 1986 and on China's experience in launching and retrieving recoverable payloads, the capsule would serve as a platform for scientific experiments and as a motivation for creating a new industrial high-technology base. If approved by the Chinese government when the next five-year plan is formulated in 1995, the capsule would be launched from the Jiuquan

Launch Center by a modified Long March 2E rocket. The current version of the CZ-2E can lift 9.2 tonnes into low Earth orbit.

B. Earth-Orbit Flight Operations

The launch of United States Shuttle Endeavour on 2 December initiated the longest and most successful extra-vehicular activity ever conducted in orbit: repair and upgrading of the Hubble Space Telescope. During the 11-day mission, two teams of astronauts conducted five two-person spacewalks from 4 to 8 December, and installed new 12.2 m European-built solar arrays (the original panels had caused oscillations of the telescope due to thermal stresses); replaced the wide-field planetary camera with a new one (including corrective optics to compensate for the main mirror flaw); installed the corrective optics space telescope axial replacement (COSTAR) to correct the "vision" of the spacecraft's other three instruments; installed new stabilizing gyroscopes (three had failed); replaced miscellaneous electronic controls, Earth-sensing magnetometers, a solar array controller, and a spectrometer power cable; and installed additional computer memory. Subsequent checkout proved all the replacements and repairs to be fully successful, and in January the telescope became fully operational up to the limits of its original design capability (see below).

The first United States Shuttle flight of 1994 year was STS-60, launched on 3 February with orbiter Discovery carrying Spacelab 2. The $13 million Wake Shield Facility, developed to test a method for manufacturing ultrapure semiconductor crystals, was to be deployed on this flight but deployment did not occur due to a sensor malfunction in the facility's attitude control system, probably as a result of electromagnetic interference from a Shuttle power line. It was instead operated within the Shuttle payload bay, verifying its operational characteristics but not allowing the expected purity of product due to the contaminated environment. The first Russian cosmonaut to fly aboard a United States Shuttle, Sergei Krikalov, operated the facility for NASA. An investigative panel concluded on 2 August that there were no technical flaws in the facility's design or construction that would preclude future success, and a reflight is planned for May 1995.

Shuttle Columbia was launched on 4 March with the United States Microgravity Laboratory (USML-2), to conduct 13 days of experiments on crystal growth, metallurgy, and a number of medical, biological, and engineering studies associated with building and operating the space station. The mission included the second flight of the 190-kg Mephisto microgravity oven, developed by six French companies under contract to the French space agency, CNES. The Mid-deck Zero-Gravity Dynamics Experiment (MODE) investigated fluid-spacecraft interaction and spacecraft structural dynamics using a miniature space structure to verify dynamic analyses of future large space structures such as the space station.

On 9 April, Shuttle Endeavour carried into orbit the Shuttle Radar Laboratory with its $366-million Spaceborne Imaging Radar C/X-band Synthetic Aperture Radar (SIR-C/X-SAR). This 10.5-tonne international payload, built jointly by NASA's JPL, Germany's space agency, and Italy's space agency, provided precision images of Earth features such as forests, wetlands, and mountains, with detailed data on environmentally important parameters such as soil moisture, rainforest flooding, snow distribution, ocean currents, and volcanic structure before landing successfully on 20 April. Also on board was the first NASA-National Institutes of Health (NIH) joint experiment, a special cell culture system carrying muscle and bone cells. During flight, changes in cell growth and development were recorded for post-flight analysis to facilitate better understanding of bone loss and muscular atrophy in both astronauts and aged patients on Earth.

A subsequent flight attempt of the Space Radar Laboratory (SRL) aboard Endeavour on 18 August was scrubbed when the orbiter's engines shut down 1.9 seconds before launch after one of them exceeded its "redlined" temperature, apparently due to a faulty flowmeter that increased the oxygen/fuel mixture ratio on Engine No. 3. The flight was later launched on 30 September after replacement of the three main engines. During this 12-day mission the Space Radar Laboratory successfully recorded results of the eruption of the Klyuchevskaya volcano on Russia's Kamchatka Peninsula, which occurred a few hours after the launch, and tracked the tsunami generated by a Richter Scale-8 earthquake off Japan's Hokkaido island on 6 October. The SRL also studied twin volcanos in New Guinea, the Teide volcano in the Canary Islands, Cotopaxi in Equador, and Mount Pinatubo in the Philippines, with the goal of learning how to forecast these natural disasters. Interferometric measurements combining data from this flight with those of the previous SRL mission in April produced topographical maps able to detect surface shifts with a resolution of a few centimetres. Observations of Hawaii's Kilauea volcano, for example, revealed that the volcano's south flank is peeling away at a rate of about 10 cm per year.

On 8 July, Shuttle Columbia orbited the most complex Spacelab flight ever launched, International Microgravity Laboratory-2 (IML-2). The seven member crew included Japan's first female astronaut, heart-surgeon Chiato Naiko-Mukai. IML-2 carried 82 experiments developed by over 200 scientists from 13 nations covering a broad range of subjects in materials science, medical research, microgravity acceleration measurement and countermeasure assessment, and technology development. The European science experiments were supported online from remote stations in France, Netherlands, Italy, and Germany. Life-sciences experiments aboard IML-2 were particularly noteworthy: Medaka fish became the first vertebrates to mate and reproduce in space; newts hatched and survived, and key radiation effects crucial to long human exploration missions were studied, including the recovery and repair of cell damage caused by spacecraft-penetrating radiation. On 20 July, the crew celebrated the 25th anniversary of the first manned landing on the Moon, returning to Earth two days later after what proved to be the longest shuttle mission to date.

Following the launch of Shuttle Discovery on 9 September, astronauts Mark Lee and Carl Meade successfully tested a new, simple rescue device called the Simplified Aid for EVA Rescue (SAFER) during the first untethered spacewalk conducted by the United States since 1984. The 38 kg SAFER device carries only 1.35 kg of gaseous nitrogen propellant. The mission's main payloads were a 2,700 kg Lidar In-space Technology Experiment (LITE), which generated profiles of clouds, aerosols, dust, and chemicals in the atmosphere, and the Shuttle Plume Impingement Flight Experiment (SPIFEX), to determine the effects of the Shuttle's maneuvering jets on nearby objects. SPIFEX results were especially relevant to the forthcoming Shuttle-Mir flight operations (see above). Preliminary data indicated that the effects are no worse (and in some cases less severe) than those predicted analytically. The Discovery crew also deployed a 1300 kg Shuttle Pointed Autonomous Research Tool for Astronomy (Spartan-201) satellite for 40 hours and retrieved it for return to Earth. The satellite collected solar wind data during its mission. Discovery landed in California on 20 September, one day later than planned.

Space Shuttle Atlantis was back in the inventory for a 3 November flight with ATLAS-03 and CRISTA-SPAS-01. The orbiter was at Rockwell's plant in California from October 1992 to May 1994, where it was refitted to allow 16-day missions and was equipped with a Russian docking system and airlock in preparation for its 1995 mission to Mir. NASA plans call for an average of eight flights per year in the future.

The first Russian Federation Mir flight operation this year, the return of the Soyuz-17 on 14 January carrying Cosmonauts Vasily Tsbiliev and Alexander Serebrov back to Earth after a six-month mission, was marred slightly by the Soyuz bumping into the space station during an inspection of Mir by the cosmonauts after their departure from the station. There was no major damage to Mir, and the cosmonauts returned safely to Earth. The same mission also brought a Russian medical doctor, Valeri Polyakov, to Mir on 10 January for a planned 14-month stay (he is scheduled to return on 15 March 1995). In November, Polyakov broke cosmonaut Musa Manorov's record of 541 days spent in space.

The Mir resupply spacecraft Progress M-24, launched on 25 August, missed its automatic docking with the space station twice on 30 August, consuming most of its maneuvering fuel. Mir was manually brought to a successful docking with the Progress spacecraft by cosmonaut Alexander Malenchenko, using a television camera aboard the M-24 to guide his control of both spacecraft. The maneuver rescued the ESA mission scheduled for October (M-24 carried nearly 300 kg of equipment for that mission) and avoided the prospect of a premature return to Earth by Dr. Polyakov. Failure of the automatic docking was later traced to a malfunction of the Kurs radar in the rendezvous/docking system aboard the Progress spacecraft. Subsequent spacewalks by cosmonauts Malenchenko and Musabayev on 9 and 13 September revealed no damage to Mir due to the incident.

The Progress M-24 also carried to Mir the first of the Shuttle-Mir experiments, the Tissue Equivalent Proportional Counter (TEPC), a linear energy spectrum analyzer calibrated in biological units, and the Space Acceleration Measurement System (SAMS). These two instruments will be deployed to measure the environment aboard Mir for the definition and support of future experiments. The Mir interface processing system (MIPS) is an IBM Thinkpad computer configured to operate the experiments and collect the data. When not active in such functions, it runs a software routine to observe single-event upsets. During a spacewalk on 14 September, cosmonauts Malenchencko and Musabayev installed mounts for one of the space station's solar panels in a new location, to make room for the United States Shuttle Atlantis when it docks with Mir in June 1995 (see above).

On 4 October, the first ESA cosmonaut to occupy Mir, Germany's Ulf Merbold, was launched to the space station aboard a Soyuz TM-20 from Baikonur Cosmodrome. He was accompanied by Russian cosmonauts Alexander Viktorenko and Elene Kondakova, both of whom will spend six months aboard the station. Merbold was scheduled to return to Earth on 3 November, along with Malenchencko and Musabayev, after conducting 22 life science experiments, five materials processing experiments, and three technology studies. During the mission, a power failure on 11 October caused by a computer short-circuit required transfer of flight control to a backup computer. Although operations were returned to normal by 15 October, failure of a furnace needed by Merbold required postponing five of his experiments until after his departure from Mir.

C. Life Sciences

The Second NASA/Uniformed Services University of Health Sciences International Conference on Telemedicine for Remote Health Care and Disaster Response, held 8-10 September, focused on the development of standards for telemedicine protocols and their implementation, along with complementary standards for infrastructure development and disaster response planning.

In November 1993, NASA formally launched the Telemedicine Demonstration Project - Spacebridge to Moscow. This project, which involves several universities and medical centres in the United States, as well as NASA, connects the United States to a Russian medical centre via a satellite network, and successfully provided consultation in a number of medical disciplines from September 1993 to June 1994. Agreements on joint telemedicine efforts are now in place between NASA and Russia, the Ukraine, and Kazakhstan, and work is in progress with the Pan-American Health Organization, UNESCO, and institutions in other countries to define further agreements that will expand telemedicine and global health programmes.

One of these programmes, the Global Monitoring and Human Health Program, begun by NASA in the mid-1980s, showed that satellite remote sensing data can identify mosquito-producing rice fields weeks in advance of actual mosquito population increases. Studies this year aimed at mapping areas of potentially high malaria transmission risk in southern Mexico identified villages at risk with 90 per cent accuracy. On the basis of this success, NASA is now defining the requirements and identifying field study sites in Africa, Asia, and Latin America for a dedicated health-monitoring satellite system.

A major initiative to develop a Neurolab Spacelab devoted to research in the neurosciences under the auspices of the United States National Institutes of Health (NIH) and NASA was defined in 1994. Participants in the project include the CSA, CNES, the German Space Agency (DARA), ESA and NASDA. Other NASA/NIH cooperative endeavours include Spaceline, a database for space life sciences research findings and data modeled after the NIH Medline data base, jointly funded grants (for example, to the Center for Vestibular Research at Northwestern University), and several joint flight research activities such as the Shuttle-borne muscle and bone culture growth experiments described earlier.

V. SPACE EXPLORATION

A. Astronomy and Astrophysics

On 23 December 1993, NASA's Goddard Space Flight Center terminated operations of the Cosmic Background Explorer (COBE) after three years of successful operation (the spacecraft was designed to last one year). One of COBE's most important observations was its verification of the microwave and infrared background radiation variations predicted by the "Big Bang" theory of the Universe's formation.

On 13 January, the first images from the repaired Hubble telescope were released, demonstrating the clarity originally projected for the instrument and verifying its ability to make the observations needed to achieve its scientific goals. On 25 May, NASA announced that the telescope's Wide Field Planetary Camera had discovered a 500 light-year-diameter gaseous disc, apparently under the influence of an extremely high gravitational field at the centre of galaxy M87 in the constellation Virgo about 50 million light-years from Earth, rotating at the enormous speed of 2 million km/hr. The strength of such a gravitational field implies a mass of at least 2 billion suns concentrated in a region smaller than the entire solar system. The implications of this discovery, perhaps the most important yet by the Hubble telescope, are that the motion of the disc is caused by a black hole in M87 – the first observational evidence that such a phenomenon actually exists.

The Russian Federation's Space Research Institute (IKI) announced on 1 February that development of the 5.6-tonne Spectrum-X astronomy satellite was still on schedule for a December 1995 Proton launch from the Baikonur Cosmodrome, despite problems caused by inflation and the many organizational changes that have taken place in that country's space programme. The follow-on to the existing Granat class of satellites will carry instruments built by the United States, Germany, the United Kingdom, Denmark, Italy, and Israel, in addition to its main instrument, the Russian-built 12-m Sodart telescope.

On 12 September, NASA added two new missions to the Small Explorer spacecraft roster, a Transitional Region and Coronal Explorer (TRACE) proposed by Lockheed to study the Sun's magnetic fields, and a Wide Field Infrared Explorer (WIRE) designed by JPL, Cornell University, and Ball Aerospace to explore the evolution of galaxies. WIRE will carry a 30 cm solid hydrogen-cooled telescope to enable observation of starburst galaxies 500 times fainter than those detected by the Infrared Astronomical Satellite (IRAS) 10 years ago. Each spacecraft will weigh only 225 kg and cost $50 million. They are scheduled for launch in 1997 and 1998 on Pegasus XL rockets.

A balloon-borne experiment using the French Pronaos telescope, designed to test instruments for ESA's Far Infrared Space Telescope scheduled for launch in 2005, was flown on 17 September from Fort Sumner, New Mexico (United States). The $16.4 million, 2,500 kg telescope was to conduct sky surveys in the sub-millimetre-wave band from the helium-filled balloon's planned 37 km altitude. The balloon, however, unexpectedly began to lose altitude about 12 hours into the planned 31-hour flight due to clouds that blocked solar heating of the balloon's helium; moreover, the telescope's star-tracker did not operate properly. Pronaos was too heavy for operations from France's balloon launch facility, which is limited by neighborhood safety considerations to payloads no heavier than 900 kg. Despite the only partial success of the mission, France plans a reflight in mid-1995.

On 5 October, ESA initiated procurement of the 4-tonne X-Ray Multi-Mirror (XMM) astronomy spacecraft by issuing a one year $24-million contract to Deutsche Aerospace. The spacecraft procurement contract for an estimated $290 million is expected next year. Full programme cost, including launch (planned for 1999) and operations, is expected to be about $750 million.

B. Solar System Exploration

Results of the Mars Observer Failure Investigation Board, released by NASA on 5 January, indicated that management errors were at the heart of the problem that caused the failure. The board found "a number of spacecraft design flaws and poor operating procedures" by both NASA's JPL and Martin Marietta Astro Space (then GE Astro Space), motivated mainly by the need to reduce costs and spacecraft mass on the fixed-price contract, which the board declared was poorly suited to a highly complex, one-of-a-kind spacecraft. The actual failure was probably caused by nitrogen tetroxide (the oxidizer propellant) leaking from its tank into the propulsion system piping, where it mixed with the fuel, monomethyl hydrazine, and exploded during the pressurization process prior to inserting the spacecraft into Mars orbit. The oxidizer had leaked through check valves, commonly used on commercial satellites. Had the Mars Observer been equipped with the isolation valves usually used for interplanetary spacecraft, the board said, the leakage may not have occurred.

The Clementine satellite, developed on a low-cost "fast-track" programme by the United States Naval Research Laboratory under contract to the Ballistic Missile Defense Organization (BMDO), was launched to low Earth orbit on 25 January by a Martin Marietta Titan-2G. It carried two star trackers, a camera for the ultraviolet and visible spectra, cameras for the near infrared and long-wave infrared spectra, a Laser Imaging Detection and Radar (Lidar) sensor, and a data-compression experiment designed and built by the French space agency CNES for eventual use on the Russian-led mission to Mars in 1996. The six sensors weighed from 0.3 to 1.9 kg each. On 3 February, the spacecraft propelled itself into a lunar trajectory and subsequently into orbit around the Moon. Beginning 20 February, its Lidar sensor mapped the Moon in 11 different wavelengths until 3 May. It was the first visit to the lunar region by a United States satellite in 22 years. The total cost of the programme, including launch, was $75 million.

Unfortunately, on 7 May during an Earth gravity assist maneuver in Clementine's transfer to a planned rendezvous in August with the asteroid 1620 Geographos, the spacecraft computer failed, draining most of Clementine's hydrazine propellant and inducing a high spacecraft spin rate (about 80 rpm). The remaining propellant was not sufficient to complete the mission to Geographos, so mission planners attempted to establish it in an elliptical Earth orbit to continue sensor testing (one of BMDO's primary motivations for supporting the mission) until October. However, insufficient electric power prevented continued operation of Clementine's subsystems, and the Moon's gravity pulled the spacecraft into a solar orbit on 20 July. The Air Force office which now manages the project is discussing with NASA several options for an equal-share follow-on mission.

On 23 March, NASA's JPL released photos that showed a small (1.6 km) moon orbiting the 56 km asteroid Ida. The photos were taken by the Jupiter-bound Galileo spacecraft on 28 August 1993 during a close flyby (10,800 km) of the asteroid. The photos provided the first real evidence that asteroids do have satellites, as was theorized nearly a century ago. The miniature moon was later named Dactyl.

The 370 kg Ulysses spacecraft, a joint $750 million project of ESA and JPL launched in 1990, surveyed the Sun's south pole from 26 June through November. On 13 September it was 300 km above the Sun's south pole, at 80.2 degrees south solar latitude. The spacecraft carries nine instruments supported by over 100 scientists in 12 countries. New information already obtained from the mission is that the solar wind issuing from the south pole travels at almost 900 km/sec, about twice as fast as the equatorial velocity observed from Earth, and that there apparently is an as-yet unknown mechanism that controls the flow of cosmic rays in the heliosphere. Ulysses also has detected hitherto unobserved long-period waves in the solar magnetic field, which may help explain the puzzling cosmic ray data. The spacecraft is scheduled to study the solar north pole beginning in May 1995, and will then swing by Jupiter in 1998 for another pass over the Sun's poles around 2000, when solar activity is at the peak of its 11-year cycle.

In late April, the RSA notified its international partners that the Mars-94 mission, originally scheduled for launch in October 1994, would be postponed for two years until the next Earth-Mars launch opportunity. In July, the Agency joined NASA in planning a 1998 mission to complete the studies never performed by the United States Mars Observer and also to send a Russian rover to the Martian surface. The spacecraft, which could replace the second United States Mars Global Surveyor and the second of the Russian Mars missions (originally Mars-94 and Mars-96), would be launched by a Proton rocket and carry a French balloon experiment and two United States instruments in addition to the rover.

In early September, NASA selected the landing site for the 270 kg Mars Pathfinder spacecraft and its miniature (16 kg) solar-powered rover, scheduled to land on 4 July 1997. The site is a rocky flood plain, Ares Vallis, about 850 km southeast of where Viking-1 landed in 1976. Mars Pathfinder will use airbags to cushion its landing after aerobraking into the Martian atmosphere and parachuting to the surface. It is the only remnant of the United States Mars Environmental Survey (MESUR) mission.

On 8 July, NASA picked Martin Marietta to build the first Mars Global Surveyor under a $54 million contract. The Mars-orbiting spacecraft's cost will be kept low by using spare parts from six of Mars Observer's eight science instruments, a lightweight composite satellite bus frame to help reduce the spacecraft mass to 965 kg (allowing use of a Delta-2 booster instead of the larger Titan-3 which launched Mars Observer), aerodynamic braking to circularize the spacecraft's Mars orbit, and Mars Observer spare parts for electric power, command and data handling, and attitude control subsystems. It is scheduled to be launched in November 1996, a month earlier than the Mars Pathfinder, and will orbit Mars during Pathfinder's exploration of the surface. The United States plans to fly the remaining two Mars Observer instruments, a gamma-ray spectrometer and an infrared radiometer, on the second Surveyor in 1998 (see above), as well as a second Pathfinder-type lander.

Plans for subsequent biennial missions to Mars include a major international cooperative effort in 2003: a Russian mission to land rovers on the surface, another United States Surveyor in orbit, and a four-lander Intermarsnet ESA mission launched by an Ariane-5. A sample-return mission is being discussed for 2005 or 2007. The international Mars working group which is coordinating the multinational assault on Mars consists of the United States, Russia, ESA, Germany, Japan, France, the United Kingdom, Italy, and Finland.

Between 16 and 22 July, 21 major fragments of Comet Shoemaker-Levy 9 crashed into Jupiter at speeds up to 60 km/s. Because the impacts occurred on the far side of the planet, only the Galileo spacecraft, on its way to a rendezvous with Jupiter in December 1995, was in position (about 200 million km away) to observe the impacts directly. The spacecraft's solid-state camera photographed six of the impacts, including two of the larger ones (Fragments K and L); its near-infrared mapping spectrometer measured the heat radiated from four of the impacts, including the largest, Fragment G; its photopolarimeter radiometer observed five of the impacts; and its radio emissions monitor recorded information from the other six. Because of data transmission limitations imposed by Galileo's inoperative main antenna, transmission of the first photos to Earth was not completed until the last week of August.

The event motivated the United States House of Representatives' Committee on Science, Space, and Technology to request NASA to submit a plan by February 1995 for the agency, in cooperation with the United States DOD and the space agencies of other nations, to locate, identify, and catalogue within 10 years all comets and asteroids more than 1 km in diameter which cross the Earth's orbit. Three candidate plans were proposed on 16 September, all using existing ground-based telescopes.

After a spectacularly successful four-year mission to map 98 per cent of Venus's surface by radar and demonstrate for the first time the use of aerobraking to reduce orbital altitude, the thrusters of the United States Magellan spacecraft were fired to lower its periapse to 137 km. Controllers lost contact with Magellan on 12 October, during orbit number 15,032, after which it was presumed to have plunged into the planet's atmosphere. Before its destruction, maneuvers during which the Venusian atmosphere acted on Magellan's paddle-like solar panels provided information on the Venusian atmosphere and additional data relevant to aerobrake design of future spacecraft.

C. Search for Extraterrestrial Intelligence (SETI)

Following the 1 October 1993 termination of United States government funding for SETI, a private nonprofit organization, the SETI Institute, was formed to raise funds to continue the programme. On 3 January, the Institute announced it had raised $4.3 million toward the $7.3 million needed to support the programme through June 1995. This will allow completion of the advanced signal processors and telescopes initially funded by NASA (this equipment is being loaned by NASA to the Institute) and six months of observation from Australia's Parkes Observatory. Approximately $3 million per year would then be needed to support the planned programme, which would use the 300 m Arecibo, Puerto Rico, radiotelescope. The Institute has dropped plans for an all-sky High Resolution Microwave Survey using JPL's 34 m radiotelescope.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

1. Earth to Orbit Propulsion

The Technology Reinvestment Program of the United States Advanced Research Projects Agency (ARPA) provided $22.2 million for hybrid rocket development to an industry team consisting of American Rocket Company, Martin Marietta, and United Technologies Chemical Systems, which will add another $10 million in funding. The Hybrid Technology Option Project (HyTOP) will conduct four development and two qualification tests on a 1.12-MN thrust hybrid booster engine. The first test under this programme was successfully conducted on 5 October on Development Motor No. 2 (DM-02), attaining 1.07 MN thrust for 20 seconds (DM-01 was tested in 1993). The engine test programme will be followed by a suborbital flight test scheduled for September 1996. The flight-test vehicle (HyFlyer) will be recovered from the ocean after a 15 minute flight carrying a 3-tonne payload to 400 km altitude.

Several new cooperative propulsion programmes were initiated this year between United States and Russian Federation corporations. Pratt and Whitney's Space Propulsion Division (United States) is now the exclusive marketing representative for the manufacture, sale, and use of propulsion systems developed by NPO Energomash (Russia). The company also signed a cooperative agreement with NASA and NPO Energomash for test firings of RD-700 tripropellant engine injectors.

Aerojet (United States) will adapt and market a United States version of the 1.5-MN throttleable NK-33 liquid oxygen/kerosene engine developed by the Samara State Scientific and Production Enterprise (TRUD, of Russia), which could be used to increase the payload delivery performance of Delta and Atlas launchers. Aerojet is also marketing TRUD's 400-kN oxygen-kerosene NK-31/39 engine to Orbital Sciences Corporation (OSC) for a potential Pegasus upgrade. Sample engines have already been delivered to OSC, McDonnell Douglas, and Martin Marietta. Aerojet also signed an agreement with Moscow's Lyulka Engine Design Bureau to improve, market, and co-produce Lyulka's 400-kN thrust hydrogen-oxygen D-57 upper-stage engine, which is throttleable and can deliver specific impulse in the range 448-461 seconds, depending on nozzle type. On 26 September, the company signed an agreement with Russia's Chemiautomatics Design-Development Bureau (CADB) to co-develop and market derivatives of the 2-MN thrust hydrogen-oxygen RD-120, which powers the core stage of the Energiya launcher. One such derivative would be a tripropellant (dual-fuel) version that could be a candidate for NASA's next-generation reusable launcher (see above).

The former General Dynamics Space Systems Division, now Martin Marietta Astronautics Space Systems Division, signed an agreement in April with NPO Energomash (Russia) for development and use of the RD-180 engine as an alternative main propulsion system for the Atlas launcher family (This agreement was signed prior to Energomash's abovementioned arrangement with Pratt & Whitney, and hence represents an exception to that otherwise exclusive agreement). The RD-180 is a half-scale version of the RD-170, which powers the Zenit launcher; it has a smaller turbopump and two engine chambers instead of the RD-170's four.

European firms have also entered into cooperative agreements with companies in the Russian Federation. France's Societe Europenne de Propulsion (SEP) has signed several contracts for liquid-propulsion technology, and in June 1993 joined with the Fakel Design Bureau (Kaliningrad) and the United States firm Space Systems/Loral to develop electric thrusters via International Space Technology, Inc.

In Japan, development of the H-2's first-stage LE-7 engine was completed in February. The 1.08-MN oxygen/hydrogen engine, whose specific impulse is 445 seconds, had accumulated a total operating time of 4.34 hours during 283 ground-test firings. The LE-7 test programme included six captive firings of the entire first stage, culminating in a full-duration 350-second firing. The second-stage LE-5A, which also uses oxygen and hydrogen propellants to generate 122 kN thrust at a specific impulse of 452 seconds, had accumulated 4.8 hours on 182 test firings. Both engines performed successfully during the H-2's maiden flight on 4 February (see above).

ESA's Ariane-5 propulsion development programme proceeded on schedule this year. The third test firing of the 230-tonne, 5.9-MN thrust P230 solid rocket motor booster took place on 20 June 1994, lasted 130 seconds and resoled earlier problems with propellant consistency. A fourth successful firing was conducted on 30 September; three more such firings are planned. On 12 April, an explosion and subsequent fire occurred 15 seconds into a planned 320-second HM-60 Vulcain engine test firing; the cause was attributed to friction between the impeller and casing of the liquid oxygen turbopump. Testing is continuing at a German test stand while repairs are being made. Programme delays are not expected; the engine successfully underwent a 10-minute firing on 22 April and has gone through 179 tests to date, encompassing over 45,000 seconds. Qualification testing was scheduled to be completed by the end of 1994. The first flight engine passed its preliminary acceptance tests and was shipped to SEP for integration into the stage, which was scheduled to undergo its first test firing at Kourou in November. The L-9 Auestus third-stage engine completed a full-duration (23-minute) ground test run.

NASA Langley Research Center released studies on 28 August of a new launch concept called "Maglifter," which uses magnetic pulses, similar to those that now drive magnetic levitation trains at speeds up to 500 km/hr, as a booster stage for an orbital vehicle. The superconducting magnets could be used to boost a single-stage rocket vehicle weighing as much as 90 tonnes to a velocity of about 1,000 km/hr from a pressurized tubular guideway 5 km long. The vehicle would emerge from the guideway in a 45-degree trajectory at an altitude of about 3 km after one minute's acceleration. The guideway would be built on a mountain slope.

2. In-Space Propulsion

In the United States, United Technologies Chemical Systems completed static testing of Orbus 21D, its commercial version of the 2.33 m diameter first-stage engine of the Inertial Upper Stage (IUS). The new engine has a propellant mass of 9,800 kg and an average thrust of 193 kN; it uses a carbon-phenolic nozzle exit cone instead of the carbon-carbon used on the IUS. It will power the upper stage of the new commercial

Lockheed Launch Vehicles LLV-1, LLV-2, and LLV-3 (see above).

Royal Ordnance (United Kingdom) completed design verification testing of the 600-N LEROS mixed-nitrogen-oxide/hydrazine dual-mode engine scheduled for use on the Martin Marietta A2100 spacecraft series. Royal Ordnance has also qualified a United Kingdom production source for a 1-N hydrazine engine.

In September, China announced the availability of a perigee kick motor, the EPKM/FG-46, which will compete with the United States Thiokol Star series motors used in Hughes and Martin Marietta satellites. The first planned use of the 6,000 kg, 1.7 m diameter motor is on Asiasat-2, a Martin Marietta Series 7000 satellite to be launched aboard a CZ-2E rocket in May 1995. The EPKM/FG-46, manufactured by the Hexi subsidiary of China Aerospace, has a glass fibre motor casing and a carbon-carbon fibre nozzle.

In Ukraine, the advantages of stationary-plasma thrusters (SPTs) and anode-layer thrusters (ALTs) have been combined to extend satellite life and reduce power consumption. Thrusts of 20-80 mN at specific impulse levels of 1,000-2,000 seconds were obtained with cathodes having low operating temperatures (900-1,000K).

On 27 January, an SPT-100 electric thruster was successfully tested aboard the Russian Gals communication satellite that had been launched on 20 January. Built by the Fakel Design Bureau of Kaliningrad, the thruster is the key element in the stationkeeping propulsion system currently being marketed for use aboard United States and European satellites by International Space Technology, Inc. The company is a consortium formed by Fakel, the Moscow Aviation Institute, SEP of France, and Space Systems/Loral of the United States

In-orbit testing was expected to be conducted on two electric thrusters, an ion rocket (25 mN at 3000 seconds of specific impulse) slated for use in north-south stationkeeping, and an electrothermal hydrazine thruster (300 mN at a specific impulse of 290 seconds) of Japan's Engineering Test Satellite (ETS-6). However, failure of the Liquid Apogee Propulsion System (LAPS) on 29 August (see above) will probably preclude this testing programme.

3. Hypersonic Propulsion

The United States national contractor team for the former National Aerospace Plane (NASP) programme, which has now been downscaled to a five-year, $500 million Hypersonic System Technology Program (HySTP), conducted fueled tests of a one-third-scale supersonic combustion ramjet (scramjet) Concept Demonstrator Engine (CDE) on 14 and 18 July. The 10-second and 30-second tests used hypergolic silane to react with oxygen in the airflow, igniting the hydrogen fuel. Fifteen tests conducted through September at Mach 6.8 subsequently determined engine flow rates, evaluated inlet operability, and assessed engine performance. Thrust levels were 10 per cent higher than expected, inlet compression exceeded predictions, and engine mass flow was within 3 per cent of design estimates. Fifteen more tests at the NASA Langley Research Center facility were planned to take place by the end of 1994. The primary goal of the HySTP programme, formally initiated on 1 October, is to demonstrate scramjet performance at Mach 15 during 1995-2000 by flying 13-kN to 22-kN thrust scramjet engines aboard surplus missile boosters

In the German Hypersonic Technology Programme (Saenger), a new ram combustor and two-dimensional nozzle, both cooled by liquid hydrogen, were operated at simulated flight speeds up to Mach 6.8.

In Japan, ground testing of a quarter-scale model of the ATREX engine demonstrated 4.2 kN thrust and 1,400 seconds specific impulse. ATREX is a combined-cycle engine that operates as a turbojet at low speeds and a fan-boosted ramjet at supersonic and hypersonic Mach numbers. It is planned for use on the flyback booster of a two-stage-to-orbit spaceplane.

B. Power

NASA's total budget for space power activity was reduced this year to about $6 million at the Lewis Research Center, the lead centre for space power research, and to about $1 million at the Jet Propulsion Laboratory. Areas of activity include photovoltaics, where emphasis is on concentrator and multi-bandgap cells; electrochemical energy storage, focusing on improving nickel-hydrogen batteries and fuel cells; high-density power management and distribution; and thermal control, including electronics able to operate over a wide temperature range by using diamond films, silicon carbide materials, and chips equipped with miniature heat pipes. As an example of the need for improved thermal control in small packages, the small rover planned for the Mars Pathfinder mission will carry three radioisotope heater units because the temperatures on Mars can fall below -40 degrees Celsius.

On 29 December 1993, the United States Department of Energy (DOE) defined the specific efforts to be included in its sharply reduced nuclear space power and propulsion programme. The $80 million DOE funding for 1994 was devoted mainly to producing Pu238 fuel pellets for the radioisotope thermoelectric generator on NASA's Cassini mission to Saturn (about $48 million) and closing down the SP-100 space reactor development programme (about $22 million). On 14 October, however, the DOE announced its intent to terminate all spacecraft radioisotope power source development and manufacturing support to NASA beyond the Cassini mission launch in 1997, a decision which could seriously prejudice plans for a joint United States-Russian mission to Pluto.

Studies to be funded by the balance of DOE's 1994 budget include a nuclear-reactor-powered advanced communication satellite ($3 million), "bimodal" power systems (formerly called "dual-mode") that produce both propulsion and power for satellites ($4 million), continuing ground tests (flight test plans have been cancelled) of the Russian Topaz-2 thermionic reactor (uncertain funding, probably by the Defense Department), and thermionic research studies (less than $2 million). The communication satellite study, which is being conducted by a team of Martin Marietta, NPO Energia, and five other United States companies (TRW, Rockwell, General Atomics, Allied Signal, and ThermoTrex), focuses on advanced technologies, power levels from 25 kW to 100 kW, and long orbital lifetimes (15 years). Its final report was due in December 1994. In July, DOE also sponsored a $75,000 study by International Space Enterprises (United States) to explore the feasibility of a nuclear reactor, based on the Russian Topaz-2 design, for lunar base functions such as powering telescopes and lunar rovers.

The first shipment of plutonium-238 fuel for spacecraft radioisotope electric generators from the Russian Federation to the United States was made in February after the signing of an agreement covering several such shipments. The first shipment was valued at $6 million. Four more Topaz-2 space nuclear reactors, purchased by the United States Defense Department to supplement the ongoing ground-test programme (see above), were flown by a Russian Antonov-124 to the University of New Mexico test site in Albuquerque on 31 March.

On 15 September, Hughes Communications International announced the first use of gallium arsenide (GaAs) photovoltaic arrays aboard a fixed-price commercial spacecraft, the Malaysia East Asia Satellite (Measat), scheduled for launch in 1995. The GaAs solar cells provide 18.5 per cent efficiency, a 40 per cent gain over the 13 per cent normally obtained from standard silicon cells. Measat's array will deliver 1.6 kW. Both Hughes' Spectrolab and another United States company, Applied Solar Energy Corporation, also announced in September that they are developing operational multi-junction (cascade) photovoltaic cells, which use three layers of semiconductors to absorb a broad range of the solar spectrum, enabling them to deliver 22 per cent to 28 per cent efficiency.

C. Automation, Robotics, and Teleoperators

On 16 February, scientists at the Center for Extreme Ultraviolet Astrophysics in Berkeley, California (United States) announced plans to automate spacecraft operations using artificial intelligence software instead of people to monitor the instruments. By 31 August, the new system, which cost $600,000, had reduced operating costs of the Extreme Ultraviolet Explorer spacecraft, launched in 1992, from $3.8 million per year to $1.5 million. The technique could be extended from solely instrument monitoring to monitoring and control of the entire spacecraft.

On 21 March, McDonnell Douglas Aerospace announced the company-funded development of a telerobotic device named Charlotte, designed to perform tasks that supplement and support the work of human crews aboard spacecraft. The 18 kg box-shaped device can turn switches on and off and manipulate controls while human crews sleep or perform other tasks, and can also provide ground-based researchers with the telepresence needed to monitor and adjust their spaceborne experiments. The device moves about the spacecraft cabin like a spider and performs its tasks by reeling itself along a "web" of eight thin motorized cables attached to the cabin walls. It is tentatively scheduled to fly on the first 1995 Shuttle-Spacehab mission.

In August, the Dante-2 robot successfully explored an otherwise inaccessible active volcanic crater at Mt. Spurr in Alaska, United States. The 770 kg eight-legged robot penetrated more than 200 m into the crater to sample the toxic environment with its two thermocouples, ambient temperature gauge, and sensors for hydrogen sulfide and carbon dioxide. Dante-2's high-resolution digital 35-mm camera also photographed the region around volcanic vents and its laser scanner compiled a three-dimensional map of the crater's interior. Although it survived several impacts from falling rocks, the robot subsequently toppled over on 2 August when the ground gave way under one of its legs as it was climbing a steep slope on its way back to the crater's rim. An attempt on 9 August to retrieve the robot so that its structure could be analyzed for stresses failed when its tether sheared as a helicopter attempted to lift it out of the crater, but during a subsequent rescue mission on 13 August project director John Bares and a United States national guardsman successfully placed a sling around Dante-2 so that a helicopter could lift it out of the crater. Seven of the robot's eight legs had been broken during its various tumbles.

D. Environmental Effects of Space Flight

1. Space Debris

On 7 February, the upper stage of the Titan-2 rocket that launched the United States spacecraft Clementine to the Moon (see above) shattered, leaving an estimated 600 pieces of new debris. The perigee of the orbit was 240 km, so that although the pieces of debris were detected, they re-entered so rapidly that they were not catalogued because the orbits were not sufficiently stable. Since the inclination was 67 degrees, the apogee of the debris crossed both Shuttle STS-59 and Mir flight paths. The operation of the Titan II stage violated approved practice in that the propellant tanks had not been vented and depleted at completion of operations, but were locked up to preclude disturbances that might violate payload tip-off conditions. A concern had been generated on the previous mission that the venting disturbances could deplete the attitude-control system prior to completion of the long coast prior to release. The design change that prevented venting until after payload release also prevented subsequent venting and propellant depletion of the stage.

On 27 April, an Ariane upper stage, 1991-15C, broke up and 30 pieces have been catalogued in a 28,815 by 255 km orbit. On 7 May, a booster motor of the Proton used to launch Kosmos-2133 broke into a number of pieces.

In February, the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, addressing the topic of orbital debris for the first time, decided on a multi-year programme to establish a consensus on the significant technical issues. Discussions at the subcommittee's February 1995 session will focus on the data-gathering and observation campaigns which provide the fundamental data. Subsequent meetings will address explosion and collision modeling, effects of hypervelocity impacts and protective strategies, and finally the definition of cost-effective mitigation strategies. More details are available in the report of the Subcommittee (United Nations document A/AC.105/571.)

The United States National Academy of Engineering initiated a technical assessment study in 1994 year to assess the state of knowledge on orbital debris, establishing five-year and ten-year plans for research and study. The Inter-Agency Space Debris Coordination Committee (IADC), founded in 1992, includes participants from Russia, Germany, Canada, ESA, and the United States, in October, China was invited to participate. IADC will consider all of the independent and coordinated programmes of the organizations represented.

2. Atmospheric Effects

On 24 and 25 March, five major United States rocket engine manufacturers announced plans to initiate programmes to eliminate or minimize the use of hazardous or environmentally damaging materials. Motivated both by the need to comply with ever more stringent regulations and the high cost of meeting them when hazardous materials are used, they will seek methods of reducing such use. The five companies are Aerojet, Atlantic Research, Hercules, Thiokol, and United Technologies, which among them produce most of the solid-propellant rockets manufactured in the United States.

E. Space Research Facilities

On 10 March, NASA successfully deployed a 20 km tether and instrument box from the orbiting Small Expendable-tether Deployer System (SEDS-2) spacecraft, which was a secondary payload aboard a Delta launch on 9 March of a GPS satellite. The cost of the programme was $5 million. The 0.7 mm diameter tether was severed and truncated to 12 km by a debris hit on 17 March. An object as small as 0.25 mm in diameter could have caused the failure, which occurred in less than half the time originally predicted for such an event.

In April, ESA initiated a $36-million "faster-cheaper-better" programme with Aerospatiale (France) to develop and fly its first reentry capsule, the 2.8-tonne Atmospheric Reentry Demonstrator. The contract was signed on 30 September. A precursor to a manned crew-transfer craft, the capsule will be launched on an Ariane-5 demonstration flight in April 1996 to test thermal-energy distribution and landing accuracy. The aluminum capsule is equipped with a phenolic-resin-coated silica heat shield. Flight plans call for a single Earth orbit, with reentry off the west coast of South America. Three balloons deployed after splashdown will keep the capsule afloat until recovery.

From 5-8 July, a Russian IL-76 MDK airplane underwent 90 parabolic maneuvers to simulate microgravity conditions for life science experiments by 19 ESA scientists. The flights were made from Germany's Berlin-Schoenenfeld airport, marking the first use of the IL-76 aircraft for microgravity tests outside the former Soviet Union. They were made in preparation for an ESA astronaut's 135-day mission aboard ESA's Euro-Mir 95 flight.

F. Materials and Structures

The United States Technology Reinvestment Program defined cost reduction of composite materials as a priority goal in 1994, so that they can benefit general as well as aerospace applications. European studies in composite materials focused on rapid densification, automated preform, and optimization of process choices. Japan's emphasis in 1994 continued to be on the production of high-performance fibres, in which it remains the world's leader. Japan also obtained reentry heat-shield performance data on carbon-carbon and ceramic materials from the OREX reentry capsule launched aboard the H-2 launcher in February (see above).

A new design for the United States Space Shuttle's external tank features an orthogrid aluminum-lithium alloy to reduce weight while maintaining vibroacoustic strength. Advanced Material Technologies Inc. and NASA's Langley Research Center developed an optical bench structure for space experiments using a foam core and a non-outgassing carbon-carbon face sheet. NASA Langley also developed a high-thermal-conductivity thermal control system material (up to 1.1 kW/m/K) for thermal doublers.

The application of "smart structures" expanded significantly in 1994. Electrostrictive actuators were incorporated in the new Wide Field Planetary Camera installed on the Hubble telescope in December 1993 (see above) to improve the positioning performance of its fold mirror. Studies this year by the United States Wright Aeronautical Laboratory demonstrated the feasibility of piezoelectric elements for simultaneous active and passive suppression of vibration. The Naval Research Laboratory supported investigations of active structural materials for spacecraft such as piezoelectric ceramics and polymers, electrostrictive ceramics, magnetostrictive alloys, and shape memory alloys for active jitter control, disturbance rejection, and both active and passive isolators. Piezoelectric actuators were used on the United Kingdom's STRV-2 satellite to reduce the tip motion of a cryogenic cooler by a factor of about 80, and the use of similar "smart-structure" methods is being evaluated by ESA for the FIRST infrared telescope.

Advanced vibroacoustic prediction methods using fluids, represented by boundary elements, coupled to structures represented by finite elements, were applied by Germany's DASA to establish acoustic noise levels for the Columbus space-station module. Similar methods were employed by ESA and CNES to improve launch environment definition. Fluid-spacecraft interaction is being explored in the Netherlands with a small test satellite called SlushSat, which uses an array of sensitive accelerometers to collect data on the direct dynamic interaction between fluid and spacecraft structure. Past studies of fluid-structure interaction focused on the integrated effects (typically characteristic motion decay times) or fluid surface motions.

Microvibration and microdynamic analysis was used by Matra Space (France) to improve the pointing stability of sensitive science and Earth observation instruments on the Solar Heliospheric Observatory (SOHO) and the SPOT family of satellites. The United Kingdom's Institute of Sound Vibrations Research (ISVR) researched the use of these methods to monitor the functional state of satellites on orbit, gaining valuable data from the Olympus spacecraft.

On 8 August, the Georgia Institute of Technology (United States) announced development of a flat, flexible satellite receiving antenna that can be rolled up like a windowshade for shipping and storage and unrolled for flat mounting on a building's siding or roof. Each antenna must be tailor-made for its location by printing the antenna design on a sheet of fibre-reinforced teflon, but fabrication time is only 24-48 hours, and the antennas can be sent to customers rolled up in cardboard mailing tubes. The current cost of a 1 m x 1 m antenna is about $1,000, but its designers claim that the cost can be reduced to about $100.

VII. EDUCATION

A. Teaching Programmes

The ten week 1994 session of the International Space University (ISU), beginning 27 June, was held in Barcelona, Spain. Design projects for the 130 students included a global tele-educational and telemedicine system and a low-cost Solar System exploration programme. Roland Dore, former president of the Canadian Space Agency, became president of ISU on 1 October, replacing George Van Reeth.

The United States round of the 1994 Manfred Lachs Space Law Moot Court competition, sponsored by the Association of United States Members of the International Institute of Space Law and the Martin Marietta Corporation, was won on 26 March by Dan Groth and Jollene Kime from the John Marshall Law School in Chicago, Illinois. The subject of the competition was legal issues related to space stations, such as patent jurisdiction and command authority. The European round was won by students from the University of Helsinki, Finland, who debated space station damage liability, commander's authority, and intellectual property rights.

NASA convened a panel to re-evaluate reviving the Teacher in Space programme, which ended in January 1986 with the loss of the first teacher, Christa McAuliffe, aboard Shuttle Challenger.

In March, Yale University (United States) announced a new course that teaches students how to use satellite images of Earth, employing inexpensive desktop computers and imagery distributed by the United States government to study long-term atmospheric changes, monitor storms, and map mineral deposits.

In April, United States Vice President Al Gore announced the Global Learning and Observations to Benefit the Environment (GLOBE) programme to help schools and educators use satellites and other communications and visualization technologies to study the environment. Approximately $30 million in federal funding through 1996, the system's first full year of operation, will be channeled through NASA, NOAA, the United States Environmental Protection Agency, and the National Science Foundation, with the Education Department generating educational materials and the State Department coordinating multinational participation. The goal of the programme is to involve one million students worldwide by 2010.

NASA's Student Explorer Demonstration Initiative, announced on 12 May, offered $4 million each (plus launch costs, estimated at $5-6 million each) to three successful bidders who propose two-year programmes to design, develop, build, and launch payloads weighing no more than 140 kg. The programme is managed by the 78-member Universities Space Research Association, which expects to receive about 100 proposals.

On 16 July, NASA Administrator Daniel Goldin launched the agency's first six-week summer programme, "Earth to LA," to motivate 80 inner city Los Angeles students and teachers in Earth sciences studies. They will attend four weeks of pre-college lectures in math, computer sciences, planetary studies, and environmental studies at a college in Ohio and then visit other colleges and NASA centres. NASA sponsors similar programmes in the eastern United States, and expects to continue "Earth to LA" in future summers.

On 22 August, the Cooperative Student High Altitude Payload (CSHARP), designed and built by 70 students from five Colorado colleges for $17,500, was launched from Wallops Island, Virginia to an altitude of 43 km. The payload measured concentrations of ozone, water vapor, nitric oxide, and methane in the atmosphere. It was recovered by a Navy ship 32 km downrange. Funding was provided by NASA, Ball Aerospace, TRW, and Martin Marietta.

In April, ESA announced a student competition for microgravity experiments to be flown during 20-second microgravity periods aboard aircraft in November. In August, ESA selected 22 experiments submitted by students at universities in 11 nations from among 49 proposals received. Up to 30 students will fly aboard the plane during its parabolic maneuvers.

On 5 January, the Technical University of Berlin's 40 kg Tubsat microsatellite was successfully launched by a Russian Tsyklon rocket. The project cost the University $65,000. It is controlled by students from their rooftop control centre at the University.

The Moscow Aviation Institute and the French space agency CNES organized a space camp in Moscow from 17-31 July, where students designed small rockets and studied flight dynamics, propulsion, and management. Tuition, food, and lodging for the two-week programme was $1,600.

B. Public Awareness

On 21 June, the United States National Air and Space Museum premiered a new IMAX (wide-screen) film, "Destiny in Space," featuring the HST repair mission and computer-generated flyover images of Mars and Venus. The film was distributed to over 100 theaters worldwide in November.

An auxiliary 3.6 kg payload aboard DirecTV's DBS-2 geostationary orbit satellite launched on 10 August consisted of a time capsule named SpaceArc. Organized by the Rochester Museum and Science Center (United States), the capsule carries pictures, text, and songs provided by adults and children worldwide. DirecTV gave up a month's operating fuel (the satellite's planned lifetime is 12 years) to accommodate the capsule. It will be boosted into a higher orbit when DBS-2 expires.

VIII. INTERNATIONAL COOPERATION AND SPACE LAW

The Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space held its 33rd session in Vienna from 21 March to 5 April 1994. The Subcommittee continued its discussion of its three agenda items: the question of early review and possible revision of the principles relevant to the use of nuclear power sources in outer space; matters relating to the definition and delimitation of outer space and to the character and utilization of the geostationary orbit; and consideration of the legal aspects related to the application of the principle that the exploration and utilization of outer space should be carried out for the benefit and in the interests of all States, taking into particular account the needs of developing countries.

The Subcommittee agreed to suspend its working group on nuclear power sources pending any action that may be taken by the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space on revising the Principles Relevant to the Use of Nuclear Power Sources in Outer Space which had been adopted by the United Nations General Assembly in its resolution 47/68 of 14 December 1992. Some progress was achieved on the other two agenda items. More details can be found in the report of the Subcommittee in United Nations document A/AC.105/573.

Acting on the recommendation of the Legal Subcommittee and the Committee on the Peaceful Uses of Outer Space, the General Assembly, in its resolution 49/34 of 9 December 1994, agreed to take no action on revising the Agreement Governing the Activities of the States on the Moon and Other Celestial Bodies, the terms of which required the General Assembly to consider revisions 10 years after its adoption.

On 25 October 1993, the Sultanate of Brunei Darussalam became the 71st member of the International Maritime Satellite Organization (Inmarsat). The Telecommunications Department of Brunei's Ministry of Communications was designated as the official signatory. The Sultanate became the 132nd member of Intelsat in April. Mexico signed as Inmarsat's 72nd member on 20 January 1994, represented by Telecommunicaciones de Mexico, and South Africa's Telekom SA became the 73rd member in April. In July, the Bahamas became the first Caribbean Community country to join Inmarsat, raising the total membership to 74.

The Organization, at its Tenth Extraordinary Session held in London from 5-9 December 1994, officially changed its name to the International Mobile Satellite Organization and agreed that the acronym Inmarsat should continue to be used.

In December 1994, the Republic of Poland joined Intelsat as its 130th member; the official signatory is the Polish Telecommunications Company. On 22, March Austria became the 17th member of Europe's weather satellite organization, Eumetsat, and Finland changed its status in ESA from associate member to full member, thereby increasing ESA's membership to 14 nations. Applications for membership in the European Telecommunications Satellite Organization (Eutelsat) by Andorra, Bulgaria, and the Russian Federation were approved in June, bringing Eutelsat's membership to 46 nations.

On 30 November 1993, Japan and China agreed to cooperate in a broad range of programmes managed by China's State Science and Technology Commission and Japan's Science and Technology Agency. Specific efforts covered by the agreement include the collection of Earth science and North Pacific ocean data and direct transmission to China from Japan's Fuyo Earth resources satellite.

In December 1993, the directors of the French and Indian space agencies signed a cooperative agreement encompassing satellite communications, remote sensing, meteorology, ground-station operations, space mission management, and exchanges of space scientists and engineers. In September 1994, India signed a similar agreement with Ukraine's space agency, focusing on remote sensing, communications, materials processing, and joint use of ground facilities.

On 16 December 1993, United States Vice President Al Gore and Russian Prime Minister Viktor Chermomyrdin signed a comprehensive agreement on cooperation in space science programmes, including exploration of Mars and Venus, astronomy and astrophysics, and solar terrestrial physics.

United States President Bill Clinton on 16 January 1994 opened United States markets to imports of space-related equipment manufactured by companies in Israel. The agreement covers launchers, satellites, and other equipment. The French space agency CNES subsequently signed an agreement (on 11 April) to cooperate with the Israel Space Agency in research activities on small satellites, space-based environmental studies, telecommunications, and space medicine. The heads of the Russian Space Agency and the Israel Space Agency, Yuri Koptev and Yuval Ne'eman, signed an agreement during Koptev's visit to Israel in late August to promote cooperative scientific and commercial efforts, including the Russian Mars-94 mission (now scheduled for 1996), mobile satellite communication systems, and possibly Russian launches of Israeli spacecraft.

An international commercial consortium to market satellite images of Earth was formed on 24 January 1994. Based in Toulouse, France, the Eurofast consortium specializes in agriculture, forestry, and the management of rural areas. Members are France's Sotema, the United Kingdom's National Remote Sensing Centre, Germany's GAF, and Italy's Telespazio.

Also in January, ESA and the Republic of Poland signed an agreement in Paris establishing their mutual intention to cooperate in the exploration and use of outer space for peaceful purposes.

During 1994, several international associations were formed to establish global, personal telephone services using mobile satellite communication services. These developments put increasing pressure on national and international regulatory agencies to provide sufficient radio frequency bandwidth to accommodate multiple, competing systems. No other aspect of space applications has expended radio frequency demand as rapidly and in so short a time as the emerging mobile satellite service system.

In a series of actions taken throughout 1994, the German national broadcast satellite service provider implemented a policy decision to use other nations' or international organizations' space segments to provide direct broadcasting services in Germany. This decision, based primarily on economic considerations, could begin an era of substantial increase in international cooperation in the provision of national DBS services.

In March, the agreement between Russian and Kazakhstan that had been outlined in late 1993, was finalized. The agreement calls for Russia to lease the Baikonur

Cosmodrome from Kazakhstan for 20 years. Russia will continue to operate the cosmodrome, which will be shifted from military to civilian control. Since October 1957, the Baikonur Cosmodrome has launched more than 1,000 space missions.

Also in March, the United Nations Institute for Disarmament Research (UNIDIR, Geneva) published the results of a three year study entitled, "Civil Space Systems: Implications for International Security." The study surveys modern civil space technologies and systems and examines the security implications of their dual use capabilities in light of inherent threats to security in their expanding uses. The study examines aspects of international cooperation, space law, international organizations and the use of confidence building measures.

In April, using the United States Space Shuttle Endeavour, researchers from Canada, Europe and the United States applied new space imaging technology to an ecological study of Canadian forests. Researchers combined the new data with images collected by aircraft, and by French and other United States remote sensing spacecraft. There are continually expanding cooperative programmes using the combined remote sensing resources of different countries.

In April, the Bulgarian and Russian space agencies signed a five year agreement on cooperation in areas of crewed spaceflight. The respective agencies will cooperate in joint research on production of spacesuits, space equipment and food for cosmonauts.

In June, an ESA-sponsored international conference in Beatenburg, Switzerland involved 140 space scientists and policy makers discussing possible future international cooperative lunar exploration efforts. The conference focused on technological and programmatic issues and the limited acceptance of the Moon Treaty to date. Issues related to resource exploitation and management were not significantly discussed.

From 13 September to 14 October, the International Telecommunication Union (ITU) held its 14th Plenipotentiary Conference (PP-94) in Kyoto, Japan. Accelerating expansion in communication and space services and technologies and sustained growth in world telecommunication demands have put increasing pressure on the ITU to meet varying needs for planning, radio frequencies and coordination of services and systems. Plenipotentiary Conferences that were previously held at intervals of 8-10 years are now occurring at 4-6 year intervals.

At the 1994 Plenipotentiary Conference, the ITU: a) established a new Policy Forum as a means for the Union to become more effectively involved in emerging "global policy issues"; b) conducted a comprehensive review of the Union's frequency coordination and planning framework for satellite communication networks; c) adopted the ITU's first Strategic Plan, covering 1995-1999; and d) elected a Canadian expert as Director of the Radiocommunication Bureau, a position previously held by an expert from the United States.

On 19-24 September, space ministers and space agency directors from 38 nations, meeting under the aegis of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), agreed to establish a regional programme in Asia to use space technologies for economic development. Although they recognized space technologies as being critical to their nations' development, the ministers declined to take any steps toward creation of a pan-Asian space agency patterned after ESA.

In October, NASA and NASDA signed a memorandum of understanding to fly a pair of United States-built scientific instruments on Japan's Advanced Earth Observation Satellite (ADEOS), the largest satellite ever developed in Japan. The United States will supply a Total Ozone Mapping Spectrometer (TOMS) and a NASA Scatterometer to complement five Japanese experiments and a French sensor package on the satellite, which is scheduled to be launched in February 1996.

In late October, the Commission of the European Union (EU) undertook to organize a space policy for Europe that would be backed by the EU's financial and diplomatic resources. This represents a major effort by the EU, which represents Europe in world trade negotiations, to bring European space policy under the Unions's purview. The EC Commission's Directorate General 13 (Telecommunications, Information Markets and Exploitation of Research) issued a directive to European governments to deregulate their satellite equipment markets immediately. Governments have six months to respond to the directive.

In November, the Western European Union's (WEU) Parliamentary Assembly urged ESA to widen its horizons to include "very specific areas of the military space sector." The effort is intended to reduce costs and duplication and to use ESA to conduct research in certain aspects of space-based observation and anti-missile systems.

In late 1994, the Nordic Satellite Distribution (NSD) network began to provide services to Denmark, Norway and Sweden via the Intelsat-702 spacecraft. NSD is the largest single television distribution network carried on a single Intelsat spacecraft. Programming is distributed to antennas measuring 24-28 inches in diameter. The 1.4 million subscribers represent an estimated 80 per cent of the Nordic households using private satellite receiving dishes.

In December, the year's third major insured spacecraft loss made 1994 a record year for space insurance losses with claims totalling $770 million. As a result, commercial space insurance premiums are expected to increase in the near future to levels of 20 per cent or more of a spacecraft's insured value.

Several important conferences and colloquia dealing with various aspects of space law were held in 1994. These included the 37th IISL colloquium on space law, held in conjunction with the 45th IAF Congress in Jerusalem, Israel and a workshop on intellectual property and outer space organized jointly by the ESA and the European

Centre for Space Law (ECSL). ECSL's annual summer course on space law and policy was held this year in Granada, Spain.

PART TWO: PROGRESS OF SPACE RESEARCH 1994

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

A. Satellites

In January 1993, the Russian Federation launched another hydrometeorological satellite of the Meteor-3 series. In addition to the operational payload of a multichannel radiometer and other scanners for reflected solar and emitted thermal radiation, the satellite carries a radiation budget instrument (ScaRaB) which has been developed jointly by France, the Russian Federation and Germany. ScaRaB is at present the only dedicated radiation budget scanner and the first results from its use have demonstrated its successful performance in space.

Meteosat-6 was launched in November 1993 from Kourou on an Ariane launcher. The satellite was designed to provide images in three spectral bands at half hourly intervals, however, a radiometric anomaly that occasionally occurs compromises the quantitative use of the image data. Correction algorithms are being developed. Meteosat-5 is currently used as prime satellite.

Meteosat-3 continues to be operated in its position at 75 degrees west, as a joint NOAA/ESA/Eumetsat programme and provides valuable information over the Atlantic Ocean and South America.

The United States GOES-8 satellite was launched in April 1994, with another, GOES-J, scheduled for launch in April 1995. Developed by NASA for the United States NOAA, the GOES series monitors and measures clouds and radiation, and provides critical information used in forecasting weather and tracking severe storms.

China had planned to launch its first geostationary meteorological satellite, named FY-2, using the Long March-3 rocket from the Xi Chang Satellite Launching Centre in April of 1994. However, because the satellite was accidentally damaged while being tested, the launch of the satellite was postponed. The new satellite is currently being manufactured and is expected to be put into orbit in early 1996. The FY-2 meteorological satellite obtains visible, infrared and water vapour cloud images. Sea surface temperature, cloud analysis charts, cloud parameters and wind vector information can be derived from these data.

A Special Sensor Microwave/Imager (SSM/I) was launched in August 1994 on DMSP-12 (Defense Meteorological Satellite Program). The SSM/I instrument measures the microwave radiation from the Earth's atmosphere and surface, which provides data on a range of parameters, including precipitation. Other SSM/I's are scheduled for launch on DMSP-13 in April 1995 and on DMSP-14 in October 1996.

The TOMS Earth Probe-94 instrument was scheduled for launch in November 1994. This

TOMS will continue ozone and sulphur dioxide measurements begun with earlier TOMS sensors.

In December 1994, the NOAA-J mission will deploy the Advanced Very High Resolution Radiometer (AVHRR-2) and other instruments. Through multi-purpose visible/infrared imagery, the AVHRR will measure land and sea surface temperature, cloud cover and precipitation, snow and ice cover, vegetation index, soil moisture and albedo. AVHRR-3 will fly aboard NOAA-K in November 1995. AVHRR-3 has an additional capability for snow/cloud discrimination. NOAA series satellites provide valuable information that aids in weather forecasting and global change research.

ESA's ERS-1 satellite continues to provide data for oceans, land, ice and snow; atmospheric dynamics/water and energy cycles and atmospheric chemistry. ERS-2, due for launch on 25 January 1995, will be a replacement and upgrade for ERS-1; instruments will include a Global Ozone Monitoring Experiment (GOME), an Along Track Scanning Radiometer (ATSR-2) and a Precise Range and Range-Rate Equipment (PRARE).

The Indian National Satellite (INSAT-2B) launched by the Ariane-4 launch vehicle on July 23, 1993, carried a Very High Resolution Radiometer (VHRR) with resolutions of 2 km and 8 km for visible (0.55 - 0.75μm) and infrared (10.5 - 12.5μm) bands for meteorological imaging of the Earth. The data collection facility includes a half hourly full Earth coverage and sector scan capability.

B. Other Space Observations

The Shuttle Solar Backscatter Ultraviolet instrument (SSBUV)-A-03 flew aboard the United States Space Shuttle in March 1994 to monitor the Earth's ozone layer and to calibrate similar satellite-based instruments. SSBUV-A-04 was scheduled to fly in November 1994 as part of the ATLAS-3 (Atmospheric Laboratory for Applications and Science) mission, and SSBUV-A-05 is planned for an August 1995 Space Shuttle flight.

In April 1994, the Space Radar Laboratory (SRL)-1, containing the United States Spaceborne Imaging Radar-C (SIR-C) and the German/Italian X-band Synthetic Aperture Radar (X-SAR), flew aboard the Space Shuttle, with the flight of SRL-2 scheduled to follow in late September. Data from the SRL flights are being used for map-making, interpreting geological features, studying ice processes, conducting biochemical, geochemical, and soil- moisture investigations, and studying resources.

In September 1994, the Lidar (light intensification, detection and ranging) In-space Technology Experiment (LITE) was flown aboard the Space Shuttle. The LITE experiment, which included the most powerful civilian laser ever flown in space, represented the first use of a space-borne laser for atmospheric remote sensing. LITE was flown to test lidar technology and its applicability for atmospheric research.

Using two RH-560 rockets launched from Shar on 19 February 1993, the Indian Space

Research Organisation (ISRO) measured near simultaneously neutral winds, electric fields, neutral temperatures, ion and neutral composition, electron densities, electron temperatures and electron density irregularities, just at the on-set time of equatorial spread-F (ESF). Four barium blobs were released by the first rocket at 18.45 hrs in the height region of 180-300 km and simultaneously photographed from three ground-based camera stations located at Kalpakkam, Kavali and Gudivada. The second rocket, launched within 30 minutes of the first, carried an Indo-Russian Federation joint Mass Spectrometer and a high frequency Langmuir Probe to an altitude of 290 km. In order to get the temporal variability, a set of complementary experiments were simultaneously carried out from a network of stations. Ionosonde, magnetometers, HF Doppler radar, MST radar in coherent ionospheric mode, VHF and UHF scintillation receivers and optical experiments such as the Dayglow photometer, All-Sky Imaging Fabry-Perot Spectrometer and All-Sky Imaging Camera were operated in a campaign mode. The data from the above experiments constitute one of the first comprehensive data sets obtained at the onset of ESF. Detailed analysis is in progress.

C. Future Satellites

ESA's ERS-2 is scheduled for launch in January 1995, continuing the measurements of the ERS-1 with the addition of atmospheric chemistry. ERS-2 will contain the same instruments as ERS-1, as well as the ESA Global Ocean Monitoring Experiment (GOME), the British National Space Centre's (BNSC) PRARE, provided by ESA and the German Space Agency, DARA.

NASA's SeaStar mission is scheduled for May 1995. SeaStar will engage the Sea-viewing Wide Field Sensor (SeaWiFS) to measure ocean colour for use in studying ocean biology and physical processes. SeaStar/SeaWiFS is being conducted as a NASA data purchase from a commercial satellite operator, and continues the 1978-1986 data set collected by the NASA Coastal Zone Color Scanner.

In August 1995, the Canadian satellite Radarsat is planned for launch aboard a United States launch vehicle, employing synthetic aperture radar (SAR) to provide all-weather images of ocean, ice and land surfaces for use in environmental monitoring, ocean and sea ice studies and land use studies.

The Danish satellite ORSTED is scheduled for a December 1995 launch as a cooperative mission with NASA and CNES. The ORSTED project will provide a comprehensive and accurate map of the Earth's magnetic field and high-energy particle environment and will help scientists to correlate the data with ground-based data of these phenomena.

The NOAA-J (14) polar orbiting satellite is currently being scheduled for launch either late in 1994 or early 1995. This spacecraft has been re-configured for an afternoon orbital crossing time so as to replace NOAA-11 (launched 24 September 1988). The NOAA-K satellite (scheduled for launch in early 1996), will be the first spacecraft in a new series equipped with more advanced instrumentation. The HIRS/3I, AVHRR/3, AMSU-A, and AMSU-B will provide more accurate measurements at higher horizontal and vertical resolutions.

The next satellite in the Defense Meteorological Satellite Program (DMSP) to monitor th atmosphere, the ocean and the solar-geophysical environment, was successfully launched on 2 August 1994. The new satellite, designated as F-12, is in a low altitude, sun-synchronous pol orbit with an ascending equatorial crossing time of 21:15 LT. The instruments include th Operational Linescan System, Microwave Imager, Microwave Temperature Sounder, Microwav Water Vapour Sounder, Ionospheric Plasma Monitor, Precipitating Plasma Detector an Magnetometer. All DMSP data are processed at, and available from, the National Geophysic Data Center.

The Japan Meteorological Agency (JMA) will launch the Geostationary Meteorologic Satellite (GMS)-5, the successor of GMS-4, in early 1995 using the H-II rocket developed b NASDA of Japan. The operation of GMS-5 will commence in May 1995. The functions GMS-5 will be strengthened by the installation of infrared split window sensors, a water vapo channel sensor and a visible channel sensor. GMS-4 was equipped with a single infrared sens and a single visible sensor. The Space Environmental Monitor (SEM) is not included in th GMS-5 payload.

Japan will launch the Advanced Earth Observing Satellite (ADEOS) in February 199 The mission objectives of ADEOS include Earth, atmospheric and oceanographic remote sensin ADEOS will carry the Ocean Colour and Temperature Sensor (OCTS) and Advanced Visible ar Near Infrared Radiometer (AVNIR) as core instruments developed by NASDA. ADEOS will als carry six sensors from other agencies; the NASA Scatterometer (NSCAT) and TOMS provide by NASA; Polarization and Directionality of Earth's Reflectance (POLDER) provided by CNE Interferometric Monitor for Greenhouse Gases (IMG) provided by the Japanese Ministry International Trade and Industries (MITI); and the Improved Limb Atmospheric Spectromet (ILAS) and Retroreflector in Space (RIS) of the Japanese Environment Agency (EA).

The Tropical Rainfall Measurement Mission (TRMM) will be launched in August 199 The payload will be provided jointly by NASA and NASDA. NASA will provide the spacecraf TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Lightening Imaging sens (LIS) and a radiation budget instrument (CERES). NASDA will provide a Precipitation Rad (PR) and will launch TRMM on an H-II rocket.

During the last ten years China has enhanced the development of its satellite remo sensing efforts not only by using data from satellites of foreign countries received by Chine remote sensing ground stations, but also by launching several Chinese remote sensing satellite China has launched two returnable "territory satellites" for multipurpose applications and pla to launch a "resources satellite" in cooperation with Brazil. Further launches of meteorologic satellites in polar and geostationary orbits are planned.

The Indian Remote Sensing Satellite (IRS-1C) is scheduled for launch during 1995. Th will be the third in the IRS series dedicated to the remote sensing of Earth's resources. IRS-1 will carry an improved camera operating in three spectral bands in visible and near infrared regions with a ground resolution of about 20 m and another camera in the middle infrared region with a ground resolution of 70 m. It will also have a camera in the panchromatic band with a resolution better than 10 m. In addition, a wide field sensor operating in the visible and near infrared region with a resolution of 188 m and a swath of 774 km will be incorporated. IRS-1C will also have a stereo viewing capability and on board recording facility.

The Canadian Measurement Of Pollution In The Troposphere (MOPPITT) instrument was selected for flight on the NASA EOS polar orbiting platform. The launch is scheduled for 1998. It will measure the amount of carbon monoxide and methane in the atmosphere and will utilize gas correlation spectrometry to detect the emissions from the atmosphere below the satellite with a height resolution of 4 km for carbon monoxide. The results will be used to understand the atmosphere and, in particular, anthropogenic effects.

Canada will launch its first remote sensing satellite, Radarsat-1, in 1995. This satellite will be equipped with a SAR instrument, permitting operation through clouds and at night. It is a versatile research satellite, capable of operating in a variety of modes, and will provide a range of swath widths, resolutions and incidence angles. It will provide data useful in managing natural resources and monitoring ice conditions in coastal waters.

D. Applications

1. Meteorology

The first in a new series of geostationary satellites was successfully launched on April 13, 1994. Known as GOES-8, this Earth-oriented satellite carries separate imager and sounder instruments, replacing the existing geostationary satellite's (GOES-7) single instrument that performs both functions, but not concurrently. The separate imaging and sounding capability eliminates conflicts in scheduling between the imager and sounder, allowing maximum utilization of both sensors. The GOES-8 imager has a five-band multispectral capability with 10-bit precision and high spatial resolution. The GOES-8 sounder has 18 thermal infrared bands plus a visible band, all of which are sensitive to temperature, moisture, and ozone. GOES-8 was commissioned at 90 degrees west longitude, until it became operational (October 1994), when NOAA repositioned the satellite at 75 degrees west longitude. The older GOES-7 satellite was then repositioned to 135 degrees west. This established a two-GOES spacecraft operation for the first time since 1989. GOES-J is scheduled for launch in April 1995.

The previously observed depletion of the total amount of atmospheric ozone in the 1992-1993 winter in the northern hemisphere has been continuously monitored by the SBUV/2 instrument on NOAA-11. The total ozone has recovered to the average level as observed over the past five years. Continued validation of the satellite data lend credence to the observed recovery.

Observations of total ozone are also derived from observations with the TOVS (TIROS

Operational Vertical Sounder) system. TOVS measurements are derived using the HIRS/2I infrared instrument observing atmospheric emission. This allows monitoring of total ozon during the southern hemisphere winter, both preceding and during the initial formation of the south pole ozone depletion. The observations complement the measurements from TOMS.

Work continues on a tropical cyclone recurvature study. A preliminary decision tree technique based on water vapour imagery is being evaluated on all tropical cyclones which form in the Atlantic and eastern and central Pacific oceans during northern hemisphere summer and fall. The technique emphasizes interactions between upper level short wave and long wave troughs in middle latitudes and the tropical cyclone.

The infrared data gathered by the GMS and INSAT geostationary satellites have been utilized by the Japanese Experiment on Asian Monsoon (JEXAM) research project to investigate the large scale convective activity over the Asian monsoon area focusing at the period when a serious flood took place in China during the summer of 1991.

The Indian Space Research Organization (ISRO) has measured trace gases such as CH_4, N_2O, and CFCs, containing chlorine and bromine radicals, which contribute to ozone depletion and the greenhouse effect. Vertical distribution profiles of these gases are crucial for understanding their chemistry. The tropical region is characterized by a strong upwelling motion which transports these gases from the troposphere into the stratosphere of tropical and high latitude regions. Data on the vertical distribution of these trace gases in the tropical region are sparse. Two balloon flights have been conducted by Indian scientists from Hyderabad jointly with a group at the Max-Planck-Institute for Aeronomy at Lindau, Germany, and one independently with indigenous instruments. A very high growth rate (18 per cent annually) of Halon 1301 has been observed, and methyl bromide has been found to be the major source of bromine radicals in the 10-30 km height region and most of the profiles show the effects of dynamical perturbations.

2. Ocean

CoastWatch, a programme coordinated by the NOAA Coastal Ocean Program Office, has the goal of providing high resolution satellite information on the coastal environment of the United States in near real-time. Satellite products provided to CoastWatch users consist of mapped images derived from AVHRR data.

The period 1993-1994 saw the successful continuation of both the ESA ERS-1 mission (launched in 1991) and the United States/French Topex/Poseidon mission (launched in 1992). NOAA is represented by teams of principle investigators from the National Ocean Service (NOS) for both altimeters and has been actively involved in data preparation, distribution and analysis. Efforts are also underway to upgrade the archive of GEOSAT altimeter data collected from 1985 to 1989.

Sea surface topography around the Kuroshio and the Kuroshio Extension in the western

North Pacific, derived from Topex/Poseidon data, is monitored on a near real-time basis which is very valuable for operational analysis and prediction of ocean currents conducted by the JMA.

Spaceborne observations are particularly important in the polar regions, where information is difficult to acquire. Satellite observations from both polar-orbiting and geostationary meteorological satellites are operationally utilized for the monitoring of sea ice distribution in the marginal seas which are seasonally covered with sea ice.

A technique for monitoring absolute currents by combining long term altimetry with instantaneous in-water measurements has been developed and applied in two regions. In the Drake Passage, reversals of the general eastward flow were found to be unexpectedly persistent. The main result for the Azores Current was short timescale variability of the strength and position of the zonal flow. Two years of Topex sea level data have been processed to give a realistic view of the large-scale circulation of the South Atlantic at 10-day intervals: individual 200 km diameter eddies, carried within these circulation patterns, have been tracked.

Calibrations of satellite altimeter measurements of wave height against buoy data have revealed inconsistencies between measurements from different satellites. These differences have been quantified and parameters calculated to allow wave height measurements from Geosat, ERS-1 and Topex/Poseidon to be adjusted to be consistent with buoy data.

The assimilation of the ERS wind data into the numerical model has resulted in improved surface analyses in several data-sparse areas. These include the southern oceans, and the area of the inter-tropical convergence zone. The detection of polar depressions in the winter period in the seas to the northwest of Europe has also been a valuable contribution to the initialization of the numerical model. Such improvements to the analysis fields have contributed to improvements in the predictions, both in the short term and up to six days ahead.

Comparisons of bulk temperatures with ERS-1 ATSR sea surface temperature retrievals suggest that the latter has achieved its design specification of 0.5 K but with a bias consistent with the surface skin effect. Further studies with a shipborne radiometer have enabled the skin effect to be quantified.

A 10-year composite of monthly sea surface temperatures from various data sources for the North Atlantic has been produced to investigate inter-annual variability and its relationship to changes in ocean circulation at a variety of scales.

3. Geology and Land Surface Use

There is increasing interest in the spectral properties of rocks with field and laboratory spectroradiometers promising to become accepted as useful mapping and logging tools. On the satellite front, some encouraging results have started to come from the optical sensor (OPS) on the Japanese JERS-1 satellite with its improved coverage of the shortwave infrared region compared to the Thematic Mapper, despite inherent noise problems. Airborne imaging spectrometer data continue to improve. However, the lack of an operational spaceborne sensor that can fully exploit the mineral absorption features in the shortwave infrared inhibits progress in spectral remote sensing.

The most exciting area is currently radar. ERS-1's SAR (and to a lesser extent JERS-1 SAR) has shown itself capable of providing calibrated, multi-temporal data sets. Rapidly changing geological events and the processes that underline them such as volcanic eruptions and desert sedimentation can be monitored by SAR and, increasingly, quantitative use can be made of the backscatter properties of the surfaces. The potential of interferometric SAR techniques for measuring geomorphological and hazardous active geological movements is now being realized. Earthquake rupture, aseismic tectonic deformation and volcano deformation are all subjects of active research.

4. Aviation (Volcanic Ash)

The joint NOAA-FAA Volcanic Hazards Alert Plan was activated for three volcanic eruptions (Kanaga and Shishaldin in Alaska, and Telica in Nicaragua) which posed hazards to commercial air traffic and threatened United States airspace. As part of the plan, all available satellite imagery from the NOAA Polar Orbiting Environmental Satellites and GOES were examined to determine aerial coverage, vertical extent, and plume movement. The satellite analyses and ash forecasts based on NOAA transport/dispersion models were reported to the FAA for dissemination to aviation interests. A total of 11 separate alert messages were sent.

The subtraction of GOES imagery at two long wave infrared window channels has shown promise as a means of detecting volcanic ash in cloud-free areas at any time of the day. The technique has been previously shown to be useful with NOAA AVHRR imagery in Polar regions. GOES-7 imagery was generated for ash plumes from Mt. Spurr, Alaska, over the northeast Pacific on 20 August 1992 and from Mt. Lascar, Chile on 20 April 1993.

E. Data Sets

1. NOAA/NASA Pathfinder Programme

The NOAA/NASA Pathfinder Programme will generate "research/climate-quality" data sets from existing archives of operational satellite data, and will make these data available to the global change research and Earth science communities.

Reprocessing 12 years of archived AVHRR data into climate quality land surface products began in 1993. The AVHRR data are calibrated, sampled and mapped at 8 km resolution. Cloud detection algorithms are applied and appended to the data set. A 10-day composite Normalized Difference Vegetation Index (NDVI) data set will be the first climate product made available to the scientific community. Production of the 8 km and 70 km data sets for the benchmark period was completed in 1994 and is available electronically over the Internet.

Some 14 years of GOES data will be copied to a permanent archive medium and a reduced resolution data set will be made available to the climate research community. The reduced resolution data set will be hourly at 8 km resolution and a further reduced resolution set of target data at approximately 70 km resolution will also be provided. The target data will consist of radiance statistics for each target at each hour. Production of the NDVI for the benchmark period was completed in 1994 and is available through the NASA Distributed Active Archive Center (DAAC) at the Goddard Space Flight Center.

SSM/I data and products will be made available in both swath and gridded formats for the pathfinder benchmark period (August 1987 through November 1988). Full resolution, orbital swath data as well as gridded fields at 10, 20 and 40 km will be generated for the antenna temperature data. A host of climate products on monthly time scales will be provided in the gridded format. These will include precipitation, snow, surface temperature, soil moisture and vegetation index over land; precipitation, water vapour, cloud liquid water, wind speed and sea ice over oceans. The data will be made available to the climate community on CD ROMs.

The Ocean Pathfinder project will reprocess all global sea surface temperature observations from 1982 to the present using the ascending orbits of the AVHRR instruments. Uniform calibrations will be applied and algorithms will be selected to measurements. During the past year, the AVHRR data from 1988 was used as a test bench for streamlining the reprocessing procedures and hardware systems. Initial benchmark products from the United States JPL were scheduled to be ready for evaluation by the end of 1994.

2. Global Land 1 km AVHRR Data Set Project

NOAA is an active participant in the Global Land 1 km AVHRR Data Set project, which has the goal of collecting and archiving daily 1 km AVHRR data from NOAA's afternoon polar satellite, and using this data to create international consensus products. The United States Geological Survey has made an initial prototype vegetation index product available on CD-ROM for review. The project began on 1 April 1 1992 and was originally intended to last 18 months, but was extended until 30 September 1994, and will likely be extended further.

NOAA chairs the Global Land 1 km Base Elevation (GLOBE) project, which has the goal of generating a 1 km resolution raster global Digital Elevation Model (DEM) with appropriate quality measurements. The final product is scheduled for release in 1996. NOAA's Coastal Change Analysis Program (C-CAP) is developing a nationally standardized database on land cover and habitat change in the coastal regions of the United States. In 1994, C-CAP completed several projects to detect changes in emergent wetlands and uplands utilizing Landsat Thematic Mapper imagery.

NOAA's National Geophysical Data Center (NGDC) released additional portions of the Global Change Data Base (GCDB) on CD-ROM. These included a new Global Ecosystems Database CD-ROM (Disc B) and an update (1994 edition) of the Experimental Calibrated Global Vegetation Index (GVI) from AVHRR. Data on ecosystems, land cover, soils, topography, temperature, precipitation, climate models, vegetation, GVI and other data have been integrate for improved multivariate analysis on Geographic Information Systems and other software.

3. Ozone

Satellite measurements of the middle atmosphere have continued to provide monitorin information on the levels of ozone in the stratosphere and to provide new information on th chemical composition from which improved understanding of the chemical, dynamical an radiative processes are possible.

Record low global values have been observed over the past two years, influenced in par by the eruption of Mount Pinatubo in 1991. The Antarctic ozone holes of 1992 and 1993 wer the most severe on record. Ozone values at mid-latitudes of both hemispheres were abnormall low; the largest anomalies were observed in the northern hemisphere where downward trends o approximately 6 per cent per decade between 1979-1994 were observed in winter and spring Trends in the Arctic zone are smaller than in the Antarctic; this is generally attributed to the mor disturbed meteorological conditions in the north. Nevertheless, ozone losses have been detecte in the Arctic winter stratosphere and links to halogen chemistry have been shown.

Understanding of the chemical, dynamical and radiative processes in the middl atmosphere have been significantly enhanced by further collection and analysis of data from th Upper Atmosphere Research Satellite (UARS) instruments and from the aerosol channels of th SAGE II instrument, which has monitored the evolution of the sulphate aerosol cloud from Mt Pinatubo.

Understanding of the chemistry of Antarctic ozone depletion has also improved: stron spatial and temporal correlations of ClO abundances with ozone depletion have been confirmed the Arctic vortex has been shown to be much less denitrified than the Antarctic vortex, a facto which is likely to be important in the observed inter-hemispheric differences in ozone loss; nev measurements of HCl and $ClONO_2$ have confirmed theories for chemical depletion in pola regions.

Stratospheric ozone losses have also been shown to be a cause of negative radiativ forcing: ozone losses in the lower stratosphere result in cooling of this region and hence les radiation of heat to the Earth's surface. Ozone losses therefore cause a cooling trend at th surface; current estimates suggest a 15-20 per cent offset of the radiative warming due t increases in all other greenhouse gases over the past decade.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

A. The Terrestrial Planets

1. Venus

NASA's Magellan mission, which was scheduled for termination in the fall of 1994, has finished its work. The spacecraft has completed an unprecedented three-fold, redundant mapping of the planet with its synthetic radar, as well as a study of gravity anomalies over the globe of Venus. Highlights of the mission included the recognition that Venus shows no sign of organized plate tectonics, despite the presence of mountainous regions and extensive surface volcanism. The absence of oceans of water seems likely to be an integral part of the solution of this puzzle.

2. The Moon

A new approach to lunar exploration was initiated by two small missions: Planet A from Japan and Clementine from the United States. The Clementine spacecraft mapped the entire lunar surface with several instruments including a visible/near-infrared spectrometer. The huge data set is providing scientists with information about the gross composition of the large areas of the lunar surface that had not been studied by previous missions. The geophysical survey has confirmed the existence of a large impact basin on the far side of the Moon. Preparations for further lunar research are also being studied by ESA.

3. Mars

The failure of the NASA Mars Observer spacecraft to go into Martian orbit in August 1993 was a major setback for the new multi-national programme of Mars exploration. The subsequent RSA decision to postpone the launch of its Mars-94 mission to 1996 and Mars-96 to 1998 added to the frustration. New cooperative programmes, including the establishment of science networks at the planet's surface are under discussion.

B. The Outer Planets

1. Jupiter

The Galileo spacecraft continued on track for its encounter with Jupiter on 7 December 7 1995. In addition to the asteroid flybys, Galileo was able to return some scientific results about Jupiter itself, thanks to the impact of Shoemaker-Levy 9 in July 1994. The post-impact events were observed in great detail from Earth, but the impacts themselves could only be witnessed from the vantage point of the Galileo spacecraft. An attempt to make these observations was successful, and analysis of the resulting data is presently under way.

2. Saturn

Development of the Cassini-Huygens mission, a joint enterprise between ESA and NASA, is proceeding on schedule. Launch is planned for October 1997, with arrival in Saturn's system expected in 2004.

C. Small Bodies in the Solar System

1. Comets

Comet Shoemaker-Levy 9, tidally disrupted into at least 20 one kilometre-sized fragments by Jupiter at the last near encounter, impacted into Jupiter's atmosphere. Ground-based and spaceborne observations by the HST and Galileo followed this spectacular event. The resulting data are of interest for a better understanding of Jupiter's atmosphere and the internal properties of a cometary nucleus itself.

A new mission to a comet is presently under preparation at ESA. The ESA Horizon 2000 project, Rosetta, will orbit comet P/Wirtanen, and make *in situ* surface investigations utilizing two landers. The launch is foreseen for 2003 and comet P/Wirtanen will be approached in 2011.

2. Dust

Outside a distance of about 4 AU from the sun, the dust detector onboard the Ulysses spacecraft discovered sub-micron sized interstellar dust penetrating the solar system from approximately the same direction as the interstellar gas. Ulysses also detected streams of dust emitted from the Jovian system.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

A. The Earth's Middle Atmosphere and Lower Ionosphere

The middle atmosphere and lower ionosphere (20-110 km) is the focus of extremely active research involving groups in all the major nations of the world who engage in atmospheric and space research. Much of the work is coordinated with, or is consistent with, the research programmes of the Solar Terrestrial Energy Programme (STEP), which contains a major working group on the middle atmosphere and the coupling with regions above and below; and the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) programme, which is a United States-based activity with a global scale of interest and involvement. The satellite system most supportive of these interests is the Upper Atmosphere Research Satellite (UARS), which contains experiments measuring constituents, temperatures and winds in the middle atmosphere. There have been meetings of these various communities during the year, which are discussed below.

Considerable activity occurred during July and August in Scandinavia with efforts to understand the polar mesopause and the unique events that occur at those summer times. These included: (a) SCALE-93, whose aim was to study by the use of rockets and ground-based systems from northern Norway, the details of Noctilucent Clouds (NLC) and Polar Mesospheric Summer Echoes (PMSE) as observed by the EISCAT radars in Tromso; (b) NLC-93, organized from Sweden, to observe NLC by air, space (UARS) and ground; (c) and the Swedish DECIMALS rocket payloads to investigate the dynamical, electrical and chemical small-scale (100 m) structure of the Mesopause region. These are also part of a STEP project. Some interesting preliminary results are already available. These include the following: the 85 km temperatures measured by DECIMALS were very low at 130 K; the positive ion structure changed drastically near the NLC on a scale of less than 100 m; sensors for electrons, ions and oxygen atoms all registered changes as the vehicle passed through the NLC. A first published paper (in Geophysical Research Letters) on SCALE has demonstrated the existence of strong neutral air turbulence, and electron density fluctuations with scales smaller than that of the neutrals, in the PMSE height region. Theoretical developments are needed to fully explain these results. Additional results are expected to be published during 1995.

A corresponding series of measurements were carried out over Canada and the Arctic by the ANLC-93 campaign. This featured the NCAR Electra carrying the CEDAR lidar and other optical systems, and the ground-based array of three MF radars and optical systems, for example, all-sky-imagers and Fabry-Perot Interferometers (FPI), associated with the Canadian Network for Space Research (CNSR). The array is based on a 500 km triangle in the western Canada near Saskatoon at 52 degrees north. This campaign allowed the study of the dynamical state of the mesopause region during NLC conditions, and comparisons of spatial and temporal spectra of gravity waves over the 500 km array. Initial results will be published in a special issue of Geophysical Research Letters during 1995.

The above campaigns may be described as regional mesoscale studies and are of great interest to the community and within STEP. Other campaigns of a more global dimension are those of the Mesosphere Lower Thermosphere Coupling Study (MLTCS) and of Coupling and Dynamics of Regions Equatorial (CADRE), both existing within STEP and CEDAR. These were conducted in August 1994, October-March 1993, and August 1994, respectively. For both studies, a global network of radars (MF, Meteor and MST/VHF) were used to study the mean winds, planetary, tidal and gravity waves of the middle atmosphere, their temporal and spatial variability, and the interactions between them. The input of energy from below, e.g. from gravity waves and planetary waves, and from above is also studied. Radiosonde data and rockets were used in CADRE to expand the height coverage and detail of the studies. Very good data have been collected from these very reliable and productive systems. The NCAR Electra was also used during CADRE as part of the ALOAA-93 campaign, which followed the ANLC-93 campaign described above. Considerable progress was made in 1994 using UARS Dynamics data (from the WIND-II and HRDI wind measuring systems) to study the spatial variability and structure of wind systems, and compare and contrast these with the detailed temporal view available from radar systems operating in MLTCS. There will be many results of this work published in 1995.

A major initiative in 1994 has been the establishment of the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) observatory on the Norwegian island of Andoya near Andenes. This international research observatory will allow continuous studies of the physics, chemistry and meteorology of the Arctic middle atmosphere, a region now less well studied than that at middle latitudes. The uniqueness of the high latitudes is evident from the NLC/PMSE studies described above, and it is also known to be a crucial location for ozone destruction and stratospheric warming studies.

Instruments initially included a Rayleigh/Mie/Raman lidar, an ozone lidar, a VHF radar, and a scanning radiometer. They are supported by the radars at Tromso (130 km away - which include EISCAT, MF and STARE radars), FPIs, a magnetometer network, radiosondes, and rocket soundings from the Andoya range. These will allow unprecedented coverage in height and time of small scale features such as shears, turbulence, and their relationship to the winds and waves of all scales (tidal, planetary, gravity) over seasonal and long-term time scales. A fuller description of ALOMAR is found in the STEP International Bulletin, which is a valuable general resource for other material on solar terrestrial physics.

The analysis of data from UARS has continued, and a number of further results and conclusions have been published in the reporting period. Among these are the detailed study of the evolution and microphysics of the sulfuric aerosol cloud from Mt. Pinatubo using spectroscopic data from orbit. The particle sizes can be observed to grow, and the concentration of sulfuric acid to vary, with the lifetime of the cloud and the local temperature. Penetration of the volcanic aerosol into the polar winter vortices in each hemisphere has also been observed. Similarly detailed global-scale data had been obtained on polar stratospheric clouds, again in both hemispheres, revealing the dependence of their formation probability and subsequent lifetime on altitude, temperature and trace constituent abundances. Northern polar stratospheric clouds are presently formed much less frequently than their Antarctic counterparts, but may become more common as the stratosphere cools slightly and the abundances of key pollutants increase. This could have serious implications for ozone depletion in the northern hemisphere.

There were two very important international meetings in 1994 that focused on the middle atmosphere. The first was the 8th International Symposium on Solar Terrestrial Physics at Sendai, Japan in June 1994. This provided review papers on all many topics within the discipline, from the Sun to the troposphere, with an emphasis upon the middle atmosphere and the influences upon it from below (atmospheric waves) and above (solar radiation and magnetospheric particles). The COSPAR meeting at Hamburg, Germany, in July had sessions on the energetics, variability, turbulence and fine structure of the middle atmosphere. At both of these meetings results from the various campaigns and working groups discussed above were presented. This demonstrated the coherence and diligence of the global community of scientists who work in the area of solar terrestrial physics. There have been no dramatic breakthroughs in 1994, but considerable progress has been made in understanding a region which is vital to the area of global climate change studies.

B. The Earth's Upper Atmosphere and Ionosphere

The period of review has seen few new launches of rockets and satellites dedicated to studies of the thermosphere and ionosphere, but it has been an active period for data analysis and the planning of future projects.

The Swedish/German satellite Freja, which was launched on 6 October 1992, was successfully operated during 1993 and 1994. Excellent data have been obtained within the fields of auroral, magnetospheric and plasma physics.

NASA's UARS mission continues to yield important thermospheric data, for example by the WIND Imaging Interferometer (WIND-II).

The Japanese Akebono satellite was launched in 1989 and still carries a healthy set of scientific instruments that yield important data for a number of fields of study. These include the state of the plasmasphere, the escape of ionospheric ions into the magnetosphere, cusp ion precipitation and plasma motion, and substorms. Akebono will be operated for several more years and collaborative studies with Geotail and other magnetospheric satellites will be conducted.

The Pulsaur rocket was launched from the Andoya range on 9 February 1994 to study pulsating aurora and related phenomena. Pulsaur is a joint Norwegian-United States project and carried nine different diagnostic instruments. The launch was successful and valuable data were obtained in near optimal scientific conditions. The interpretation of the data is in progress.

Several relevant and important satellite missions are being prepared. The CRISTA/MAHRSI project has been mentioned in the preceding section. It focusses on the middle atmosphere, but will also yield information about the lower thermosphere. The Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) mission has been under consideration for some time, and it is now hoped that the preparations can start in 1996. Odin is a Swedish satellite to be launched in 1997. It will be designed for spectroscopic studies at submillimetre and millimetre wavelengths of astronomical objects and the Earth's atmosphere. The ODIN project will be carried out in collaboration with Canada, France and Finland. The Norwegian Ionospheric Small Satellite Experiment (NISSE) is being planned for a possible launch in 1997. The payload will fly in a circular polar orbit and its main aim will be to study ion outflow in the polar regions. The project is a collaboration between the Norwegian space physics community and groups in the United States, Canada, United Kingdom, Germany, Sweden and Denmark.

ESA's Cluster mission is of great importance for the European and North American ionospheric and magnetospheric research communities. Implementation of the project is proceeding as planned with a launch from Kouru scheduled for 1996. The planning process also includes an extensive net of ground-based observations to be conducted during the Cluster mission.

C. Planetary Atmospheres and Aeronomy

The Pioneer-Venus Orbiter spacecraft entered the Venusian atmosphere in October 1992 and burned up after 14 years of highly successful and comprehensive studies of the upper atmosphere, ionosphere and solar wind interaction processes at Venus. The data from some of the *in situ* measurements obtained during this entry period, as well as drag information, are still being analyzed and published. The lower atmosphere of Venus continues to provide evidence of fascinating large-scale cloud variability. Models are being developed which explain the symmetric distribution of carbon monoxide between the hemispheres in terms of the general circulation of the atmosphere, rather than a volcanic source as originally postulated. Analysis of the Venera-15 Fourier spectrometer results has continued, with emphasis on high latitudes. The investigation of the deep atmosphere of Venus has continued on the basis of recent ground-based observations and Galileo spacecraft observations in the near infrared spectrum. A new mission, VESAT, has been designed to further probe Venus' atmosphere with a low-cost orbiter designed to investigate these and other phenomena. If approved, this will form part of NASA's Discovery programme of planetary exploration.

The Magellan spacecraft entered the Venusian atmosphere and burned up in October 1994. During the last phase of its mission, it provided a great deal of important atmospheric information, through satellite drag and radio occultation observations.

The Galileo spacecraft is on its way to Jupiter and will arrive there in December 1995. It will deploy an atmospheric entry probe and the Orbiter will make extensive measurements of the atmosphere and magnetosphere of Jupiter. The Galileo Near Infrared Mapping Spectrometer (NIMS) observations of the atmosphere of Jupiter during the impact of comet Shoemaker-Levy 9 are being returned to Earth and analyzed. Because Galileo had a direct view of the impact site, NIMS has the potential to detect condensable species such as water vapour, hydrogen sulphide, ammonia and phosphine if significant quantities of these were injected into the upper atmosphere as a result of the impact.

The failure of the Mars Observer in 1993 and the postponement of the Mars-94 mission left planetary researchers with no chance to obtain new spaceborne data on that planet for the next two years. Nevertheless, the analysis of data from the Phobos orbiter is still in progress. Evidence of water vapour exchange between regolith and the atmosphere were found in the Infrared Mapping Spectrometer (IMS) data. The analysis of these data resulted in important conclusions about the surface composition of Mars.

MEASUR-Pathfinder is being readied for a 1996 launch. It is nominally an engineering demonstration test of the landing system, but it will also carry the following scientific instruments: an imager, an atmospheric structure cluster and an alpha-proton-X-ray spectrometer which will be deployed by a mini-rover. The Mars Surveyor spacecraft is also on schedule to be launched in 1996. It will carry the same instrument complement as the Mars Observer did, except for the pressure modulated infrared radiometer and the X-ray spectrometer.

The Mars-94 mission is now planned to be launched in 1996. It is still planned to have a very impressive and comprehensive instrument complement and international participation from over 20 countries. The Mars-96 mission is scheduled for a 1998 launch. A Joint United States-Russian Federation Science Steering Committee has been formed to look at possible joint activities under the Mars Together Programme. There have also been initial discussions and studies on United States-Russian Federation cooperation in the Fire and Ice mission; the ice component of this programme would send a small spacecraft to Pluto on a fast trajectory for a first look at this planet.

The ISAS Planet-B programme was initiated in April 1992. The programme hopes to clarify the structure and dynamics of the Martian upper atmosphere and its interaction with the solar wind. ISAS will send an orbiter to Mars in 1998 using the third of its newly developed M-V series rockets. The orbiter will arrive in late 1999 and take a low periapsis at 130 km in order to survey the most important altitude range of the Martian ionosphere. It will take a large apoapsis distance of 15 Mars radii to study the night side of the Martian magnetosphere where escaping energetic ionospheric ions are expected.

The spacecraft weighs 258 kg and is 2 m in diameter. The spacecraft spins with a period of 8 seconds and its spin axis points towards the Earth for communication purposes. About 33 kg is allocated to the scientific instruments, which consist of a three axis fluxgate magnetometer, energetic electron and ion energy analyzer, ion mass spectrometer, high energy particle detector, thermal ion drift meter, electron temperature detector, ultraviolet spectrometer, plasma sounder and HF wave detector, low frequency plasma wave detector, visible camera, dust counter, extreme ultraviolet spectrometer, and neutral gas mass spectrometer. The thermal ion drift meter, energetic ion mass spectrometer, dust counter, and neutral gas mass spectrometer are being developed in collaboration with Canada, Sweden, Germany, and the United States, respectively.

In early 1995, NASA will select for further study the next three Discovery missions and a number of the missions proposed have an atmospheric and aeronomic focus.

The Cassini mission is in the hardware development and construction phase and will be launched in October 1997. It will carry the Huygens Probe, built by ESA, which will make measurements of the atmosphere of Titan. The Cassini Orbiter will make comprehensive measurements of the atmospheres and plasma environments of Saturn and Titan.

The Rosetta mission is being studied as a joint ESA-United States mission. It is planned as a cometary rendezvous mission, which would also carry two surface landers. Such a mission would lead to a major step forward in our understanding of comets and their sources.

A vigorous programme of theoretical studies of planetary atmospheres and their plasma environment is continuing. These are a combination of data interpretation and modeling activities. Work relating to present and past water abundances on Venus and Mars and global solar wind interaction processes with non-magnetic planets are just two examples of such studies.

D. Trace Species in the Earth's Atmosphere

Work continues on improving the International Reference Ionosphere (IRI) as the internationally accepted standard model for representation of ionospheric densities, temperatures and drifts. Research teams in the United States, Brazil, Argentina, Europe, Russian Federation, India, Japan and China are focussing on particular aspects of this task. IRI is now widely used for applications in science, engineering and education. Most recently, the model was applied to obtain accurate sea surface heights from the GEOSAT satellite altimeter measurements (1985-89); the ionospheric correction in altimetric measurements is proportional to the total electron content.

An IRI Workshop was held during the 1994 COSPAR meeting, and several important additions and extensions of the model at high latitudes were introduced. The high latitude region is particularly difficult to model because it involves the complex coupling mechanisms between the thermosphere, ionosphere and magnetosphere. The inclusion of auroral boundaries and interplanetary magnetic field dependencies are required for the extension of IRI to a reliable representation of the auroral and polar latitudes. A team at the Phillips Laboratory in the United States has developed a model representation of the high latitude ionosphere that reproduces, qualitatively characteristic features, such as the auroral oval, polar hole and ionization tongue. At Izmiran in the Russian Federation, an updating algorithm was established for IRI to represent the effects of magnetic storms. Both these models will be included in the next edition of the IRI model.

An interesting task force activity took place at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy. Twelve modellers and data providers, six from developed countries and six from developing countries, met in front of computer terminals (linked to the Internet) and at round-table discussions to resolve longstanding problems in accurately modelling the plasma densities in the F1-region. The experiment was highly successful and it is planned to continue this computer-aided workshop format in 1995 focussing on a different modelling problem.

The Prediction and Retrospective Ionospheric Modelling over Europe (PRIME) programmes, being conducted under the auspices of the Commission on Science and Technology (COST) of the European Union has resulted in important contributions to regional mapping of ionospheric parameters and has established a database of ionospheric data and indices for the European sector. An ionospheric disturbance index has been proposed based on the disturbance-induced ionization enhancement or depression near the F peak as monitored by ionosondes. A database for this index and a catalogue of disturbed and quiet days has been developed for the PRIME period.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM

The study of plasmas in the solar system includes studies of such environments as the of the planets, and the extended plasma environments of comets. The bulk of our firm knowledge of the physics of plasmas in space comes from measurements made *in situ* by space probes but additional information has come from balloons, rocket probes, and ground-based facilities, such as radars.

An important new era has been opened by the Ulysses mission. In September 1994, the ESA/NASA Ulysses spacecraft crossed the south solar polar region. For the first time ever it has been possible to make measurements over a pole of the Sun. Some surprising results were obtained. Solar wind in polar regions flows much more smoothly and twice as fast as the wind studied in the ecliptic plane for the past 30 years. Its composition is also very different from the in-ecliptic wind. The di-pole magnetic field known to exist at the solar surface loses its di-pole-like character in the solar wind over the poles. It was believed that the cosmic radiation could penetrate the solar system much more easily over the solar poles than at lower latitudes but Ulysses measurements do not confirm this, and the theories of cosmic ray arrival will have to be re-examined. The spacecraft is now on its way toward a north solar pole crossing in mid-1995. The 1995 polar crossing will occur at a solar quiet time, but Ulysses will return to examine the poles again in 2000 and 2001 at which time the Sun will be active and very different results are to be expected.

The NASA SAMPEX spacecraft, launched in 1992 into a near Earth polar orbit, has studied the arrival and storage of anomalous cosmic rays in the Earth's radiation belts. It has also provided baseline information against which data from other heliospheric spacecraft can be compared.

The ICE spacecraft (originally called ISEE3) built by NASA, and carrying several European investigations, was launched in 1978 to study interplanetary space. It was later used to explore the environs of comet Giacobini-Zinner. More recently it has been used to provide solar wind and magnetic field data when ICE and Ulysses were suitably aligned in the heliosphere.

The Pioneer-10 and Pioneer-11 spacecraft launched by NASA in the early 1970s and the Voyager-1 and Voyager-2 spacecraft launched in the late 1970s, are at great distances from the Sun and are moving away with velocities of around 2.5 AU per year. They continue to study the solar wind, the interplanetary magnetic field and the cosmic-radiation and are at all times on the lookout for signs of an approaching heliospheric boundary. The actual distances in July 1994 were Pioneer-10, 60 AU; Pioneer-11, 41 AU; Voyager-1, 60 AU; Voyager-2, 43.5 AU.

The Galileo Jupiter orbiter is presently making its way slowly to its rendezvous with the planet in late 1995. In July, it was able to take images of the Shoemaker-Levy 9 comet's encounter with the planet. Analysis of the second Galileo Earth encounter in December 1992 has revealed a number of surprisingly well-defined encounters with the Earth's bow shock at anti-sunward distances as large as 340 Earth radii.

Earth's low-altitude plasma, particularly over the polar regions.

Unprecedented high resolution data continue to be obtained on the Earth's auroral regions by the Swedish/German Freja satellite. Flying at altitudes less than 1,750 km, Freja is investigating the lower reaches of the auroral acceleration region where the interaction with the ionosphere manifests itself most clearly. In 1995, launch of the FAST satellite within NASA's small explorer programme will study the higher altitude region with even higher resolution.

The large, multi-spacecraft programme, referred to as the Inter-Agency Solar-Terrestrial Programme (IASTP), to investigate plasma processes in the near Earth space is expected to get into its main phase with the launch of the first of the NASA contributions, WIND, in November, 1994. The second NASA spacecraft, Polar, is scheduled for launch in November, 1995. WIND will study phenomena in the solar wind and monitor conditions upstream of the magnetospheric system. Polar will study the distant polar magnetosphere.

The Japanese contribution to this programme, the Geotail spacecraft, has been providing exciting data since its launch in 1992. Geotail is exploring the magnetotail of the Earth's magnetosphere but because of its unique orbit is also contributing valuable dayside magnetopause data. Geotail is reducing its apogee to 50 Earth radii late in 1994 and will achieve a 10-by-30 Earth radii orbit in February of 1995.

Eastern Europe is contributing a programme called Interball to the IASTP. The mission will feature pairs of spacecraft in low and high orbit respectively with the aim of further studying the inter-relationship of ionospheric and magnetospheric processes. The first spacecraft pair, Interball-Tail, is scheduled for launch in November, 1994, the second pair, Interball-Aurora, in 1995.

This phase will be followed by the ESA-led Cluster mission, wherein four spacecraft will fly in close formation to study three-dimensional field and plasma structures in the Earth's magnetosphere and its boundaries. In particular, fundamental physics questions will be addressed from the first use of multi-point measurements in the high latitude magnetosphere. Cluster is a component of ESA's Horizon 2000 1st Cornerstone, and is to be launched on the first Ariane-5 launcher in late 1995.

The Solar and Heliospheric Observatory (SOHO), the other component of the 1st Cornerstone, with its mix of remote sensing and *in situ* measurements, will investigate solar and interplanetary processes, many of which are closely related to those pursued by Cluster and the other IASTP missions.

Active plasma experimentation in space has become well established. After the CRRES mission ceased operation in 1992, the Russian Federation's Apex spacecraft launched in December 1991, is currently performing such active experiments.

is very active, with a range of exciting space programmes. In fact, the number of spacecraft expected to be launched between November 1994 and November 1995 (12) marks an all-time high and should provide a great advance in the understanding of space plasmas. It is important to remember, though, that ground-based observations of various kinds contribute significantly to this understanding as do instruments carried on balloons and sub-orbital rocket flights.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

A. Astronomy

The last decade of the twentieth century is also the fourth decade for which access to space has been available. From such an experience one can say that today the needs of astronomy are well understood and clearly identified. These needs differ from those of the other space disciplines. Thus, further progress in astrophysics is now possible only if access to all of the electromagnetic spectrum is secured. For most wavelength bands, this requires that the relevant instruments be placed above the Earth's atmosphere. The huge effort currently being made in the area of large ground-based optical and infrared telescopes is parallel to a similar one for the ground-based facilities for the radio, sub-millimetre and Cerenkov air shower telescopes for Gamma Rays above 500 GeV. There is considerable complementarity between ground-based and space-based astronomy, the only conflicts being of a financial nature. Generally speaking, priority has been given to those spectral ranges for which the atmosphere is essentially opaque, e.g. sub-millimetre, infrared, extreme ultraviolet, X-ray and Gamma rays. As precursors to space missions, it is worth mentioning here that several balloon experiments are on-going, most of which are in the infrared, hard X-ray and Gamma ray domains.

An overview of worldwide space programmes in astronomy and astrophysics is summarized in Tables 1 and 2. These tables and the associated lists include:

- The main responsible agency or nation;
- The launch dates (actual or scheduled);
- A brief description of the main characteristics of the mission; and
- A statement on the study status (Phase A, B, C, D), for projects which have been approved.

A large number of projects and proposals have been submitted to the various agencies, particularly in response to the call for proposals from ESA for the M3 and Horizon 2000 Plus programmes. None of these proposals has yet been accepted.

Summary comments on activities in the various wavelength ranges are given below, as are brief summaries of the missions in operation and approved.

Gamma Rays

The exciting results currently being obtained by Granat and GRO indicate interesting and complex sources over the full gamma-ray domain. The selection of Integral is a logical and timely step towards the understanding of these sources.

X-rays

Currently ROSAT and ASCA are producing a wealth of remarkable data which will require a follow-up in many spectral regions. Several X-ray missions are in the pipeline before and after the turn of the century.

UV and extreme UV

HST has been repaired and now produces data at its design limit. IUE is still operational 16 years after launch. EUVE has completed its survey and now operates in pointed source mode. Several missions are approved such as ORFEUS, SPECTRUM-UV and MINISAT-1, the NASA mission FUSE has been cancelled pending the submission of a proposal for a mission of reduced scope. Thus, unless a revised FUSE is reinstated, no replacement of IUE with a second generation observatory is planned. This will be detrimental to the entire community when IUE ceases its operations.

Visible

As mentioned above, HST is fully operational. The European Hipparcos has completed its astrometric mission. The future includes Santa Maria and the Russian Federation astrometric satellite Lomonosov. EVRIS (F) and STARS are recommended missions, not yet approved, which should open up the field of asteroseismology. Several very large ground-based projects are also underway.

Infrared

ISO is scheduled for launch in 1995 and IRTS has been approved. SIRTF (United States) has suffered form some past uncertainties but is still being considered. Edison is a proposal of considerable size which deserves consideration. Taking into account the impressive developments of ground based near-infrared telescopes, the field seems reasonably well covered.

Sub-millimetre

Approved missions are RELICT-2 (Russian Federation) and the United States SWAS, a small explorer. Odin is in phase A study and projects such as AELITA and SMME_SMILS are also being considered. FIRST will be the large mission approved in this frequency band and will be the last of the ESA Horizon 2000 cornerstones. COBRAS/SAMBA has been recommended for phase A study and represents the logical follow-up of COBE but with broader scientific objectives. The airborne SOFIA (D/United States) should be operational by the end of the decade.

Radio

RADIO-ASTRON and VSOP are the first approved VLBI missions and will open up a new frontier with involvement of the ground-based VLBI arrays. Lower frequencies and longer baselines should be considered in the future.

Complementary Research

In addition to the information from the analysis of photons, astronomers have seriously considered the possibility of using other particles such as neutrinos, gravitons, and charged species (cosmic rays). While neutrino detection, for the time being, appears to be an exclusively ground-based activity, gravitational wave astronomy from space may have considerable potential. Cosmic ray studies (as distinct from investigation of heliospheric modulation) have been reasonably well covered by medium size missions in the past. At present, no cosmic ray mission is approved, although future projects exist: ASTROMAG (NASA) - a large superconducting magnet, is being considered as an attached payload for the Space Station. POEMS (NASA/F) - a Small Explorer mission, is being considered for electron-positron studies. The following programmes have been proposed for the ESA Horizon 2000 plus programme: ELISA - a large ionization spectrometer to cover the knee of the cosmic ray spectrum around 10 to the 11th power eV and diffuse gamma background; EPOS - a positron and electron spectrometer from 200 KeV to 2 GeV to determine Cosmic Ray propagation and interaction with the solar wind and the boundaries of the heliosphere; and HELEX - a detailed investigation of the local interstellar medium and outer heliosphere.

Table 1 - Missions in Operation

Year	Radio	Sub-mm	IR	Visible/UV	EUV/X-Ray	Hard X/Gamma-Ray
1978			KUIPER	IUE		
1987						MIR/KVANT
1989						GRANAT
1990				HST	ROSAT	ULYSSES
1991						GRO
1993					EUVE ASCA	

KUIPER	(NASA) Airborne Observatory. Multipurpose airborne 91 cm Observatory Facility.
IUE	(NASA/ESA/UK) 45 cm UV telescope for medium-high resolution spectroscopy Observatory mission.
HST	(NASA/ESA) 2.4 m telescope for imaging and spectroscopy of galactic and extragalactic sources. Observatory mission.
EUVE	(NASA) Whole sky survey for broad band spectroscopy of bright sources in the range 8-90 nm. PI mission, guest observer programme.
ROSAT	(D/NASA/UK) Imaging Soft X-ray and EUV telescopes for survey studies and pointed observations (0.03 - 2 KeV). PI mission + guest observer programme.
ASCA	(Japan/NASA) High sensitivity imaging and spectroscopy of X-ray sources. Observatory.
MIR/ KVANT	(Russian Federation) Imaging, spectroscopy and timing studies in the band 2-200 KeV. PI mission + guest observer programme.
GRANAT	(Russian Federation/F) Monitoring and localization of X-ray sources and low energy gamma-ray imaging. PI mission + French guest observer programme for the gamma-ray telescope SIGMA.
GRO	(NASA/D) Imaging and broad band spectroscopy (0.1 MeV - 30 GeV). Observatory.
ULYSSES	(ESA/NASA) French gamma-ray burst experiment HGS-OGRE.

Table 2 - Approved Projects

Year	Radio	Sub-mm	IR	Visible/UV	EUV/X-Ray	Hard X/Gamma-Ray
1992				FAUST ORFEUS		
1993					ALEXIS	
1994/5				SPECTRUM-UV		
1995	VSOP SWAS	RELICT-2 IRTS	ISO	IEH/UVSTAR	<-----------SAX------------> SPECTRUM XTE SAC B EURD	X-GAMMA LEGRI
1996	RADIO/ ASTRON				<-----------HETE---------->	GGS/WIND
1997	ODIN					MARS 94/96
1998					AXAF-1	
1999					XMM ASTRO E	
2001						INTEGRAL
2005	FIRST					

Projects are listed in order of waveband starting from radio and ending with Gamma-Rays

VSOP	(Japan) 10 m antenna for orbiting VLBI imaging 1.3, 6, 18 cm. Observatory in phase C.
RADIO	(Russian Federation/Eur/United States) 10 m antenna for orbiting VLBI at 1.3, 6, 18, 92 cm. ASTRON Observatory in phase C/D.
RELICT-2	(Russian Federation) Study of large scale anisotropy and spectrum of 2.7 K cosmic background radiation. PI mission in phase C.

SWAS	(NASA) 55 cm off-axis Cassegrain warm telescope for spectroscopic survey of the galactic plane in lines of H_2O, O_2, Cl, CO (480-550 GHz). PI mission in phase B.
ODIN	(S/F/Canada/SF) 1.1 m telescope for mm (119 GHz) and sub-mm (420-580 GHz). Interstellar chemistry and atmospheric ozone.
FIRST	(ESA) 3 m warm Cassegrain telescope for high throughput heterodyne and far IR spectroscopy and imaging. Observatory.
IRTS	(Japan) 15 cm cooled telescope for imaging and spectroscopy of galactic and extragalactic sources. PI mission in phase C/D.
ISO	(ESA) 60 cm cooled Cassegrain telescope for spectrophotometry and imaging of IR sources. Observatory.
FAUST	(F/NASA) Wide angle UV camera for imaging and background radiation studies. Shuttle mission phase C/D.
ORFEUS	(D/NASA) 1 m telescope for high sensitivity moderate and high resolution spectroscopy (40-120 nm). PI mission in phase C/D.
SPECTRUM UV	(Russian Federation/I) 1.7 m telescope for spectroscopy and wide field imaging (90-900 nm). Real time observatory in phase A.
IEH/ UVSTAR	(NASA) UV spectroscopy (600-1250 A) from the Shuttle. Two 30 cm diameter telescopes.
ALEXIS	(NASA) Layered synthetic spherical mirror to map the diffuse X-ray background. PI programme.
SAX	(I/NL) Imaging, broadband spectroscopy and long-term monitoring of X-ray sources (0.1-200 KeV). PI mission in phase C/D.
SPECTRUM -X	(Russian Federation/NASA/EUR) Spectroscopy, imaging monitoring and polarimetry of X-ray sources. PI mission in phase C/D.
XTE	(NASA) Temporal studies and broadband spectroscopy of compact X-ray sources (1-200 KeV). PI mission in phase B.
SAC B	(Argentina/NASA) CCD detector to study the diffuse X-ray background and X-rays from solar flares. Primarily an engineering test.

EURD	(E) UV spectrometer on MINISAT-1 (E) to monitor the diffused background from 30 to 100 nm.
HETE	(NASA) Primarily aimed at gamma-ray burst and X-ray transients but also has a UV CCD camera and a French experiment.
AXAF-1	(NASA) High resolution imaging and spectroscopy of the X-ray sky. Observatory facility.
XMM	(ESA) High throughput spectroscopy and imaging in the soft X-ray range. Observatory in phase A.
ASTRO E	(Japan/NASA) High throughput imaging X-ray spectroscopy facility - including a microcalorimeter and CCDs, for the range 0.1 - 10 KeV.
LEGRI	(E/UK) Low energy Gamma-Ray Instrument on MINISAT-1 (E) to cover the range 15-150 keV.
GGS/WIND	(NASA) Primarily to study the interplanetary medium but has two Gamma-ray burst experiments (KONUS and TGRS).
MARS 94/95	(Russian Federation) French Gamma-Ray burst experiment LILAS-2.
INTEGRAL	(ESA) Imaging and spectroscopy from about 20 keV to 10 MeV in phase B.

The following conclusions can be drawn from the above lists and tables: a) The state of astrophysical research in general and of the ever increasing part of it performed with space experiments is healthy; b) the reduction of missions by space agencies and/or nations is due to budgetary pressure rather than scientific or technical reasons; c) most of the wavelength bands require further investigation from space and it is clear that the portion of the electromagnetic spectrum from UV to Gamma Radiation cannot be explored in any other way than by space borne observatories; and d) new missions tend to be bigger and more costly - hence international collaboration and cooperation is essential. Such collaboration is recommended not only to contain costs for individual funding agencies but to avoid duplication and to implement observatory facilities so that as large a number of scientists as possible may use the data in the true spirit of science.

B. Solar Physics

The Sun is the most important and interesting star by virtue of its steady provision of energy, its variability which affects our environment, power and communication systems, and its convenience as a laboratory for cosmic physical processes. The advantages of placing solar observatories in space derive from the absence of the disturbances produced by the Earth's atmosphere and the lack of absorption. These features of operation in space allow imaging of fine structures and observations of the electromagnetic spectrum beyond the ultraviolet cutoff. Most of the solar atmosphere, because of the high temperatures reached in the upper chromosphere and corona, is best observed at shorter wavelengths in the ultraviolet, extreme ultraviolet and X-rays. Thus, solar emission is best observed from space.

The main problems addressed in space solar physics remain those related to the transfer of the mechanical energy resident in the convective motions of the lower, cooler photosphere upwards and to the conversion of this energy to the other forms of energy that are responsible for the heating and activity of the corona and the acceleration of the solar wind. Both problems require observations of the solar atmosphere on the smallest possible scale since it is clear that some of the crucial physical processes are very localized. It is also necessary to simultaneously detect the entire solar spectrum in order to encompass all the possible temperature regimes of the Sun.

The previous major solar space missions, such as Skylab and the Solar Maximum Mission, have made significant contributions to the understanding of the solar atmosphere and its activity by allowing coordinated studies over a wide range of wavelengths including visible, UV, X-ray and gamma ray photons. This emphasis on coordination is one of the key elements in most of the major future programmes for solar physics. Furthermore, from lengthy experience in solar observing and the need for collaboration with colleagues in many nations to overcome the day/night cycle in gathering data, the solar physics community has a long and successful history of international collaboration which is fully exploited in planning space missions.

1. Currently Operating Solar Programmes

Two main thrusts are provided by the currently operating solar programmes. The first covers the study of solar activity in an attempt to understand the flare phenomena and with the ultimate goal of achieving sufficient knowledge to forecast flare and other coronal activity which can strongly influence the interplanetary and terrestrial environment. The second objective is to observe the Sun with instruments that address a broad range of unanswered scientific questions regarding the nature of the inner corona, the extended corona and the acceleration of the solar wind. The investigation of the sources of the solar wind is also crucial for the problem of mass loss from the Sun and ultimately for stellar evolution.

In 1991, the Japan's ISAS launched Yohkoh, the only long duration mission totally devoted to solar observations during the current cycle. The four instruments on Yohkoh are designed to study high energy solar flare activity, the global coronal structure and the irradiance variations of the Sun. Yohkoh is carrying: the Soft X-Ray Telescope, a collaborative United States-Japanese experiment, which is imaging the soft X-ray corona and a Bragg crystal spectrometer developed jointly by experimenters in the United Kingdom and in the United States. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing much better sensitivity and resolution than the imaging detectors previously flown on the Hinotori and Solar Maximum Mission satellites. Higher energy X-rays and gamma rays are also monitored by the Yohkoh instruments.

Yohkoh has produced many new results and has observed thousands of flares. Its excellent spatial and temporal resolution have revealed the highly dynamic nature of the solar corona with changes of the coronal magnetic structures taking place very suddenly. With Yohkoh, the process of magnetic reconnection was for the first time actually observed to occur in solar flares and active regions. Yohkoh has discovered active region brightenings with a frequency of occurrence as a function of their energy which is a continuous extension of the similar distribution for flares. This implies that small events ("microflares") are not over-abundant. This result is important in relation to the problem of heating of the solar atmosphere since it may rule out microflares as the source of coronal heating. New information has been obtained on the evolution of coronal streamers and the related occurrence of Coronal Mass Ejections.

A campaign of simultaneous observations of the Sun was organized to study the geometry of magnetically confined plasmas in the solar atmosphere, which included Yohkoh, the United States Solar Plasma Diagnostic Experiment sounding rocket and several ground-based observatories. The campaign has produced a very rich data set. Support for Yohkoh operations is planned to continue at least through 1997.

The NASA solar physics programme uses flight opportunities from the Space Shuttle to conduct investigations of the corona with Spartan 201. Spartan is a retrievable, autonomous satellite that permits up to two days of solar observing time. A white light coronagraph and an ultraviolet coronal spectrometer study bulk flow patterns and acceleration mechanisms of the inner solar wind. The instruments undertake UV spectroscopy and white light polarimetry of the extended solar corona from 1.5 to 6 solar radii from the Sun's centre, thus allowing measurement of temperature, densities and bulk outflow velocities of electrons, protons and several minor ions. The resulting description of the extended corona can be used together with theoretical studies to identify and understand the physical processes involved in solar wind acceleration.

The first Spartan 201 mission flew in April 1993. The second took place in September 1994 when the ESA/United States Ulysses mission reached its maximum latitude over the Sun's south pole. While Ulysses conducted *in situ* sampling of the solar wind high in the heliosphere above the Sun, Spartan performed remote sensing of the source regions for the same solar wind observed with Ulysses, the first such simultaneous observations. These cooperative observations will be repeated in the summer of 1995, as Ulysses passes over the Sun's north pole. Finally, in 1996, Spartan 201 will fly simultaneously with the ESA/United States SOHO mission as a calibration mission.

Coronas is a series of Russian Federation satellites designed to observe the solar atmosphere from near Earth orbit, and to observe solar activity and magnetospheric solar effects. They will carry a number of instruments developed by groups from the Russian Federation, in collaboration with groups from many other countries. The instruments include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as detectors for helioseismology, dedicated to the indirect investigation of the solar interior.

The Solar Station Coronas-I was launched in March 1994 and is currently in operation. The 11 instruments of the scientific payload cover a wide region of the electromagnetic spectrum from radio to gamma rays. Particles are also detected. The main instruments are an imaging X-ray telescope and spectroheliograph (6 intervals in the 2-304 Å spectral range) having spatial resolution of a few arcseconds, an optical photometer for measuring solar oscillation, a radiospectrometer, a set of hard X-ray and gamma ray spectrometers operating in the range of 1-2 MeV.

While no hardware collaboration existed between the United States and the Russian Space Agency for the Coronas programme, a Participating Scientist Programme will be supported in 1995 for the encouragement of operational and data analysis cooperation for this mission.

Other currently operating missions that are of special importance for solar studies, but not primarily dedicated to solar physics, include Ulysses, Granat and the Gamma Ray Observatory (GRO).

Ulysses, launched in October 1990, is an exploratory mission carried out jointly by ESA and NASA. Its primary objective is the study of the interplanetary medium and solar wind as a function of heliolatitude. The solar physics objectives of Ulysses encompass the study of the structure of the interface between the Sun and the solar wind/interplanetary magnetic field, solar radio bursts, solar X-rays and solar cosmic rays out of the ecliptic plane. In September 1994, after a journey of almost four years, Ulysses reached its maximum latitude during the first ever pass over the south pole of the Sun of a man made probe. Ulysses is spending a total of 234 days above 70 degrees latitude during its first polar pass. The second polar pass, over the north pole, is expected in the summer 1995. Ulysses has already sent back a wealth of extremely valuable information from the polar regions on the properties of the high latitude solar wind and interplanetary magnetic field.

The Granat satellite, launched in December 1989 by the Russian Federation, and whose main objective is the mapping of the gamma ray sky, has observed over 100 high energy solar flares in the energy range from 100 keV to 100 MeV. Several gamma ray flares have substantial emission above 10 MeV. The 2.23 MeV line resulting from the deuterium synthesis reaction during solar flares has also been detected. These data can address the problem of the directivity of high energy solar emissions.

The GRO, one of the major NASA missions in high energy astrophysics, was launched in 1991. GRO is well-suited to observations of the solar X-ray and gamma ray radiation and accelerated neutrons which are the most energetic phenomena taking place during solar flares. The flare emission is observed in the energy range from 50 to 1000 keV and above 20 MeV. The region of the spectrum including the gamma ray lines observed during energetic solar flares is also covered. The GRO data allow an extremely accurate measure of the energy spectrum of the non-thermal radiation of the Sun.

2. Missions Currently Under Development

ESA and NASA are planning a July 1995 launch for SOHO, one of the most ambitious solar physics space science missions developed so far. The predominantly European scientific payload of SOHO comprises eleven instruments including six built in collaboration with groups in the United States. The SOHO instruments will probe the entire Sun, from its centre by means of helioseismology to its outer atmosphere by remote sensing in the visible and in the ultraviolet spectra. Simultaneously, the solar wind will be probed at 1 AU by *in situ* studies. SOHO will thus study the interior and the atmosphere of the quiet Sun addressing the problems of the internal structure below the photosphere, of the heating and generation of the corona, and of the acceleration and composition of the solar wind. Special emphasis is placed on high spectral/spatial resolution of the inner corona and on observations of the extended corona out to 30 solar radii. These observations will determine the main physical properties of the solar coronal plasma in regions far from the solar surface, where the acceleration of the solar wind takes place.

The SOHO spacecraft will be placed at the Lagrangian point between the Earth and the Sun to avoid the confusing effect of orbital velocity present in low Earth orbiting missions. From this unique vantage point, 1.5 million km in front of the Earth, SOHO should have an unprecedented view of solar phenomena and is expected to clarify the main unsolved problems of our nearby star. The life of the mission is expected to be 2-6 years. The European-United States cooperation in SOHO includes the staffing of a common operations centre at NASA/Goddard Space Flight Center for day-to-day operational decisions and collaborative research as the data are returned open to the worldwide community which will also participate in the SOHO mission by providing ground-based solar observations.

The second Coronas station is currently under development in the Russian Federation. Named Coronas-F, its launch is scheduled in 1996. The payload will include improved versions of the instruments of Coronas-I, with increased resolution of the X-ray telescope of 700 km or less on the Sun. Coronas-F will also observe spectral lines in the region of 3-7 Å. The third solar mission in the Coronas programme is Foton, scheduled for launch after Coronas-F. The main instrument will be a large solar gamma ray telescope.

NASA has very recently selected the Transition Region and Coronal Explorer (TRACE) programme as its first solar physics small explorer spacecraft. The objective of the TRACE mission is to directly observe the connections between the small-scale magnetic features that characterize the photospheric magnetic field and the larger scale structures that are seen in the solar corona, thus pursuing the discovery by Yohkoh that the corona is a continuously dynamic atmosphere that responds to impulses from the photosphere.

TRACE will survey this connection from the photosphere into the corona, with unsurpassed temporal and spatial resolution (about 400 km on the solar surface). For this reason, TRACE is expected to make major contributions to our understanding of the mechanism of coronal heating. The TRACE instrument is designed to isolate narrow UV and EUV spectral bands containing emission lines formed in the chromosphere, transition region and corona. The TRACE spacecraft will be launched in 1997 into a Sun-synchronous orbit.

The Satellite de Aplicaciones Cientificas-B (SAC-B), the first satellite mission of Argentina, carried out in collaboration with NASA with the participation of the Brazilian and Italian space agencies, is scheduled for launch in 1995. SAC-B will carry a detector suite to study X-ray emissions from solar flares in the 2 to 300 keV energy range, with spectral resolution of up to 1 keV at low energies and a temporal resolution of few tens of milliseconds. These instruments are being built by CONAE (the Argentine space agency) and NASA's Goddard Space Flight Center.

Several other countries have solar physics programmes that include balloon observations, with instruments dedicated to flare physics.

The NASA programme includes a long-duration Antarctic balloon investigation, the Flare Genesis Project. Flare Genesis, to fly in December 1995, seeks to break the spatial resolution barrier of ground-based observations using an 80 cm telescope and a vector magnetograph.

As an intermediate experiment designed to facilitate the development of the Space Solar Telescope (SST) in China, a balloon-borne solar telescope with an 80 cm aperture size has been approved and is now being manufactured. The balloon flight will test the SST systems and all related subsystems and also observe at high resolution the fine structure of the Sun's magnetic fields. The balloon-borne telescope will be launched around 1996.

3. Future Solar Programmes

Future solar space missions continue to focus on understanding the problem of chromospheric and coronal heating, namely the coupling of sources of energy in coronal activity with structures and changes of magnetic fields and plasma motions in the solar outer atmosphere. Significant advances in this field require major improvement in the resolution of the instruments and the use of stereoscopic techniques to define the geometry of the magnetic confinement of the plasma in the solar atmosphere.

The High Energy Solar Imager (HESI) is a candidate in the United States programme for investigating particle acceleration in solar flares during the 2001 solar activity cycle maximum. Suggested tools for such studies involve imaging spectroscopy in hard X-rays and gamma rays.

Following the highly successful Hinotori and Yohkoh solar missions launched by the Japanese ISAS in the previous solar activity maxima, the Japanese solar physics community is preparing to launch a Sun-observing satellite at the time of the next solar activity maximum around the turn of the century. The mission, Solar-B, is under discussion at the present time.

Solar-B would be launched by ISAS around 2001 and could involve collaboration between the solar physics communities in Japan, the United States and the United Kingdom. The model payload includes an optical telescope capable of making photospheric images with a spatial resolution of 200 km on the solar surface and of measuring magnetic and velocity fields in the photosphere, and an X-ray imager for the diagnosis of coronal plasmas having temperature of 0.5 to 10 million K. Line broadening in transition regions and coronal emission lines, which may be manifestations of energy input into the corona, can be observed with an XUV imaging spectrograph. A Sun-synchronous orbit will be chosen to minimize the effects of observing time gaps and of line shifts due to spacecraft motion.

The Solar-B proposal will be evaluated by the ISAS science committee in 1995 for a launch as the 20th Japanese scientific satellite, using the newly developed M-V booster, in 2001.

The SST was proposed in China in 1992. The telescope system will consist of a diffraction-limited optical telescope with a 1 m aperture, spectrographs, and attached telescopes for the UV, soft and hard X-rays. The satellite carrying the telescope will be placed in a polar circular orbit at 500 km from Earth. Launch is planned in 2001-2002, around the maximum of the next solar cycle. The major scientific targets are to achieve a breakthrough in solar physics by coordinated high resolution observations of the magnetohydrodynamic processes in the solar atmosphere. The telescope will obtain two-dimensional spectra, magnetic vector fields, velocity fields and images in the visible, UV and X-ray spectral ranges.

The Solar Interferometric Mission for Ultra-high Resolution Imaging and Spectroscopy (SIMURIS) was studied by ESA in the framework of the Space Station Attached Payloads programme and recommended for a second phase of study in 1992. Uncertainties in the Space Station programme have delayed the start of this second phase though specific studies were conducted up to the end of 1993 by ESA's Space Station and Microgravity Directorate to accommodate a reduced version of SIMURIS on the External Viewing Platform of the Columbus Module. A free-flyer mission was also investigated and proposed to ESA.

The thrust of SIMURIS is to investigate the very fine structure of the Sun through the use of ultra-high spectral, temporal and spatial resolution. SIMURIS can be considered a unique mission capable of observations at the same spatial scale as some of the processes occurring in the solar atmosphere, i.e. smaller than 0.1 arcsec (70 km on the Sun). Besides its temporal and spectral coverage, the SIMURIS mission proposes a UV imaging interferometer from 1175 to 2800 Å with ultra-high spatial (20 km on the Sun), spectral and temporal (50 m) resolutions. The interferometric co-phasing technique has been proven in the laboratory and could be applied to future larger interferometric missions.

A cooperative United States, Russian Federation, European, and Japanese programme for a heliospheric probe mission consisting of two spacecraft to graze the Sun's corona at about 4 and 10 solar radii, is also under consideration. These spacecraft would carry a variety of miniaturized *in situ* instruments and imagers for testing all current beliefs concerning the Sun's outer atmosphere some time after 2000. The mission is at present foreseen for the years

2000-2005.

Current and planned activities in the field of solar physics involve extensive international cooperation and a rich variety of research goals over the next decade. With the advent of new communications technology, a longstanding tradition of such cooperation in solar research will be strengthened in the future.

VI. LIFE SCIENCES AND SPACE RESEARCH

The space life sciences find themselves in transition in a number of different ways. Fundamental results have accumulated from past missions and research projects to the extent that critical questions have emerged that will require an increasing presence in space to answer. Confirming data are presented by each space mission that the long-term research capabilities that the developing international space station should provide will be essential to for fully investigating life using microgravity as a fundamental research tool. The space radiation environment presents both opportunities for further biological discoveries, and challenges for living systems to survive. Simultaneously, robotic missions to other planets and new observations of space have highlighted our awareness of space as a place where the origin and evolution of life on Earth may have been shaped, and elsewhere may be being duplicated.

A. Gravitational Biology

Gravitational and space biology has entered an interesting phase in its relatively young history. This phase is marked by the necessity to reflect thoroughly on the data that have been accumulated, especially on the data collected over the last ten years in which the methodology of carrying out experiments in space has been improved considerably. Dedicated microgravity research facilities, such as the Russian Federation Biocosmos satellites and the United States Space Shuttle/Spacelab combination, as well as the utilization of the Space Shuttle's mid-deck capabilities and those of the Russian Federation's Space Station Mir, have been instrumental to the performance of an increasing number of well-controlled biological research projects. The results obtained must now be reviewed to identify the most interesting and promising research avenues to be taken in the near future. Such a review process has been initiated by a number of national and international space organizations, as well as by the scientists concerned. It is clear that the transition is being made from a period of obtaining new scientific observations of life in weightless conditions, to a period in which an understanding of the underlying biological mechanisms will be examined, using microgravity as a tool.

This does not mean that all relevant observations have already been thoroughly documented. Due to the relative scarcity of flight opportunities for life science experiments (and all of those experiments still require repetition and independent confirmation), the knowledge base still needs to be firmly established. Nonetheless, it is already obvious that gravity appears to play an important role at all levels of life, from single cells to plants, animals, and human beings, during at least some periods of their lives and in at least some of their constituting systems.

Supporting observations span such areas as, for example, the mechanics of human breathing under microgravity conditions to areas such as the molecular machinery involved in transduction of chemical messages in a single cell.

The 30th Scientific Assembly of COSPAR clearly reflected this state of affairs: results were presented that either confirmed or shed a different light on earlier results, and many papers were presented that raised questions about possible mechanisms that could contribute to an understanding of earlier results. It is fair to state that the mechanisms involved in producing the observations made in microgravity are still far from being understood. It is also fair to state that because of those intriguing puzzles, the scientific community concerned is extending its research capabilities to involve, much more than in the past, Earth-based facilities that can either produce short-term microgravity conditions (drop towers, parabolic flights, sounding rockets) or to functionally simulate certain of the aspects of weightlessness (clinostats, neutral buoyancy facilities). Certain standard biological models have been proposed that could provide the intellectual framework within which new studies could be initiated.

Nevertheless, there are still two major obstacles for the life science community that hamper the development of the gravitational research field up to a level that would allow continuous research programmes to be run within a normal academic environment, and with the involvement of undergraduate and postgraduate students. These include the scarcity and often uncertainty of flight opportunities and the lack, in many nations, of funding and opportunities to perform the relatively low cost, but highly relevant space related research on the ground.

More than a decade of research by dedicated scientists in the life sciences has produced a rather surprising new set of observations, and a concurrent awareness that much more can be done on the ground if provisions would be made accordingly. A prerequisite to achieving an understanding of the role of gravity in living systems is the development of, and continuous access to dedicated research facilities, both on the ground and in space.

B. Planetary Biology and Origins of Life

The scientific community continues to further define and develop the history of life and life-related molecules in the universe, from the birth in the stars of the elements important to life, to their processing in the interstellar and forming stellar environments, to their inclusion in planetary systems and the origin of life on at least one planet and possibly billions more. Spaceflight-obtained data and missions to the Earth and other planets of this solar system are essential to an understanding of life in the universe, and scientists (exobiologists) committed to understanding the origin, evolution, and distribution of life in the universe have benefitted from recent space research. The COSPAR Sub-Commission on Planetary Biology and Origins of Life has the stewardship of COSPAR's planetary protection policy, which stipulates safeguards to be taken against the biological contamination of other solar system bodies and any possible contamination of the Earth's biosphere from spaceflight missions. Recent highlights in the emerging science of exobiology are discussed below.

Disks of dust have been seen (via the HST and other observatories) around a high percentage of newly formed stars, confirming theories about the birth of planets. The likelihood of the widespread existence of extra-solar planets reinforces star formation models that predict planet formation is a common phenomenon. Furthermore, recent models indicate that planets may form regularly at a distance permitting liquid water, a quintessential ingredient for life.

Laboratory experiments with low-temperature ices have delineated the temperature dependent nature of reactions that may occur on astronomical ices. The efficacy and nature of photochemical products may lead to an assessment of organic material found in comets.

The Ulysses mission detected interstellar gas and micron-sized grains of interstellar dust flowing into the solar system. Interstellar and interplanetary dust may have played a significant role in the prebiotic chemistry of early solar system planets.

Laboratory experiments have shown that simple phosphorylated aldehydes can be concentrated, ordered, polymerized with the aid of surface active, catalytic minerals, to form sugar phosphates related to those forming the backbone of RNA.

Directed evolution of RNA enzymes has been demonstrated in the laboratory. This work lends credence to the concept that the ancestors to today's ubiquitous DNA-protein based microorganisms could have been based on RNA. Furthermore, the technique represents a fundamentally different approach for creating biomolecules with widespread pharmaceutical and biochemical applications.

Eleven morphotypes of fossil micro-organisms have been identified on Earth from chert 3.5 billion years old. This field research indicates that life had already evolved to a fair degree of complexity in only a few hundred million years on Earth into a form that is remarkably similar to modern photosynthetic cyanobacteria.

Studies of the paleosol (ancient soils) data suggest that the content of Earth's earliest atmosphere may not have had concentrations of carbon dioxide sufficient to account for a warm Earth. Models of carbon dioxide for Mars show that the formation of carbon dioxide clouds should negate the greenhouse effect of high carbon dioxide concentrations. These results suggest that other trace gases may have played a critical role in providing environments warm enough for liquid water within which life could have evolved.

Other paleontological analyses have shown that major increases in the Earth's oxygen through geologic time may reflect, not a change in photosynthetic capacity, but a change in burial rates of organic carbon.

The July 1994 collision of comet Shoemaker-Levy with Jupiter has increased interest in the frequency and consequences of comet impacts in the origin and evolution of life. Regular impact events may have been a key factor in shaping life on Earth, and potentially elsewhere.

In technically related activities, a submersible Telepresence Remotely Operated Vehicle (TROV) was deployed under the ice in Antarctica, to test science-enabling robotic field techniques for planetary exploration. Included in the field test was a live international telecast, "Live From...Other Worlds", which was an educational pilot project to carried to approximately 2,000 schools. This live, interactive, pilot broadcast allowed students to view field activities, ask questions of the human participants, and to drive the TROV using a combination of Internet and satellite TV resources.

The 30th COSPAR Assembly voted to modify the international planetary protection policy on missions to Mars. This modification has relaxed some of the measures that need to be taken by a mission to meet COSPAR's overall planetary protection requirements. The new implementation is based on the current scientific understanding that there is extremely little likelihood of Earth microbes growing, unprotected, on the surface of Mars.

C. Natural and Artificial Ecosystems

In 1994, a noticeable dynamism was observed in the scientific community concerned with the theme "Natural and Artificial Ecosystems", especially in controlled ecological life support systems, in spite of a decrease in the funds made available by space agencies.

The following points should be emphasized: a) the mass of results is increasing as compared to the those presented at previous COSPAR meetings, with a manifest interest from young scientists; b) several large scale projects are proceeding, with the purpose of insuring life support in closed environments based on plant growth (NASA's Kennedy, Johnson and Ames Centers), CEEF (Closed Ecology Experiment Facilities) in Japan, co-funded by the Japanese Atomic Energy Commission, and the Russian Federation project BIOS-4, attempting to take advantage of the pioneering experiment BIOS-3, but currently in stand-by because a lack of funds; and development of closed ecosystems to support scientific investigations or to contribute to public or University-level educational tasks (at Huntsville, Alabama and Guelph University, Ontario, respectively); c) the enlargement of the F4 community to include internationally well-known scientists (Prof. B. Grodzinski, University of Guelph, Ontario, Prof. J.C. Menaut, Ecole Normale Superieure, Paris, with Australian plant physiologists and nutritionists); d) the emergence of, and the active opening to the international community of Russian Federation laboratories, especially at the Institute of Biophysics at Krasnoyarsk, headed by Prof. J. Gitelson; and e) recent and drastic staff changes on the site of Biosphere-2, in Oracle, Arizona, in order, apparently, to permit a better scientific recognition of the work being conducted there.

1. Controlled Ecological Life Support Systems

In Europe, there has been a reduction in funding for Controlled Ecological Life Support Systems (CELSS) programmes. Large space programmes, such as Hermes or Columbus are not totally closed, and alternatives to these programmes are still under definition. Nonetheless, there is no doubt in the space community that the exploration of outer space, after a robotic phase, will finally be conducted with human explorers. This assertion is illustrated by the recent proposal from ESA (and associated member states) to other countries to support a new Lunar Programme dedicated to science (Science on the Moon, Science of the Moon, Science from the Moon). Biological studies and artificial ecosystems appear in the last two phases of this proposed Programme (phases 3 and 4).

CELSS activities have induced the fast development of image processing techniques applied to plants (spectral and fluorescence methods, image recognition) in order to follow growth, to detect stresses or diseases, and to pilot harvesting robots. A development of sensors (miniaturization, use of optical techniques) has also been noted, along with an improvement of software codes optimizing the parameters in growth chambers or giving the nature and the quantity of volatile compounds accumulated in culture systems. Noticeable efforts concern trace contaminants and micro-organism related problems.

The utilization of plants in CELSS projects addresses not only productivity, but also quality aspects and the parameters suitable to control the nutritional value and the health of plants.

2. Natural Ecosystems

The concept of a simplified artificial ecosystem as a new tool to study basic and applied problems related to ecology has begun to attract well-known scientists in the international community, as mentioned above, including those not specifically concerned with space research. This attraction is especially focused on following the microbial populations associated with plants, and the interaction of trace contaminants, both of which are amplified in closed systems. A renewal of interest can be noted for the concept of a closed microcosm (a self-regulated, biologically-simplified closed ecological system). These systems often host small-scale associations of prokaryotes, micro-algae, and even crustaceans, gasteropods or fishes. A remarkable, ancient know-how pertaining to this particular topic seems to exist in the Russian Federation. In other developments, the construction of two large chambers is currently going on at the University of Guelph (Ontario) to study plant canopies, with financial support from private companies (interested in instrumentation, sensors, and horticulture).

VII. MATERIALS SCIENCES IN SPACE

Microgravity research is scientific investigation conducted in a gravitational field that is a small fraction of the gravitational acceleration on Earth. Gravity is certainly a weak force compared, for example, to atomic binding forces. Therefore, the role of gravity in physical phenomena is important only when stronger forces are in equilibrium or when special circumstances arise. The goal of materials science research in space is to use the unique experimental environment to study fundamental phenomena during solidification of melts, crystal growth and combustion, and to determine thermophysical properties of fluids. The main missions in 1994 that involved these research areas were the United States Microgravity Payload-2 (USMP-2) and the International Microgravity Laboratory-2 (IML-2).

A. Materials Science Research

The particular interest in this field is the understanding of the roles of buoyancy-driven convection, sedimentation, and hydrostatic pressure in the processing of alloys, composites, ceramics, and polymers.

Important materials science experiments were carried out on both the USMP-2 and IML-2 missions. Three prominent materials science payloads on the 14 day flight of USMP-2, were the Advanced Automated Directional Solidification Furnace (AADSF), the Isothermal Dendrite Growth Experiment (IDGE), and the Mephisto furnace. The use of telescience was an important factor on this mission.

The IDGE experiment measured the size and growth speed of single dendrites. These data will be compared to theoretical models of the process in order to identify the nature of gravity induced melt-convection on tip velocity and tip radius selection. Fifty-nine experiments were conducted over nine days. With the use of telescience, images of growing dendrites were transmitted for evaluation. Over 100 interactive changes were communicated to the IDGE. This allowed the investigators to optimize the experimental conditions.

Crystals of mercury cadmium telluride were grown in the AADSF. This material is an important semiconductor alloy. The characteristic properties of the space-grown crystals will provide new insight into the physics and chemistry of semiconductor crystal growth. AADSF operations were conducted for ten days. Telescience facilitated continuous monitoring of the experimental conditions by the ground-based personnel. This allowed the principal investigator to communicate solidification rate changes through telescience.

USMP-2 provided the second opportunity to fly the Mephisto furnace. On this flight, the cooperative United States-France project involved a series of experiments on the directional solidification of three nearly identical samples of a tin-bismuth alloy. Over 55 melting and solidification cycles were performed on the samples. The furnace operating conditions were continuously monitored by the investigators. More than 45 complex electrical measurements were made which required the use of telescience to revise the experimental procedure after evaluation of the initial data.

The IML-2 mission served as a low gravity laboratory for several materials science related experiments. Many of these experiments involved containerless processing through levitation in the Electromagnetic Containerless Processing Facility (TEMPUS) and NASDA's Large Isothermal Furnace. TEMPUS is a levitation melting facility for containerless processing of metallic samples in an ultra-clean microgravity environment. TEMPUS experiments involved the non-equilibrium solidification at large undercoolings, nucleation studies, undercooling of alloys and quasi-crystals, thermophysical properties of undercooled glasses and the viscosity and surface tension of undercooled molten metal alloys. In the NASDA furnace, samples were processed under various thermal conditions, studying ceramic/metallic composites, semiconductor alloys, and liquid phase sintering. Sintering is a process for combining dissimilar metals, using heat and pressure to join them without reaching the melting point of one or both metals. The convective stability of plane front solidification in a succinonitrile-acetone system was studied in DARA's NIZIEMI facility.

NASA, ESA, DARA, CSA and NASDA also continued to support vigorous programmes involving solidification and materials property measurement in ground-based experimental programmes and short duration microgravity experiments carried out in drop tubes and rockets.

B. Biotechnology Research

The application of biotechnology research results range from the design of new drugs, to protein engineering, synthetic vaccines, and biochip technology for the electronics industry. Biotechnology under microgravity conditions has focused on the study of isolated biomacromolecules, such as proteins, and the study of cells in controlled fluid and chemical environments. In particular, protein crystal growth has been the subject of many space experiments. Proteins are complex molecules responsible for many biochemical functions essential to life on Earth. Scientists use protein crystals to determine the structure and function of proteins. The pharmaceutical industry uses such information for the design of drugs that bind to a specific protein which can block chemically active sites. Such drugs are able to "turn off" the protein's activity, thus regulating metabolic processes.

The three-dimensional structures of proteins are determined by X-ray analysis of protein crystals. However, many proteins that interest medical researchers have not produced crystals of adequate size and quality to allow X-ray data to be collected. Crystals grown in space, where they are virtually free from the distortions of gravity, often provide better structural information than their counterparts grown on Earth.

Biotechnology was an important aspect of the IML-2 mission. Twelve investigators undertook protein crystallization experiments in ESA's Advanced Protein Crystallization Facility (APCF). The APCF provided biologically important protein crystals (that are difficult to synthesize on Earth) for analysis, and to determine the governing growth mechanisms. It was the first space facility ever designed to use three different protein crystal growth techniques: liquid vapor diffusion, liquid-liquid diffusion and dialysis.

Electrophoresis is widely used on Earth to produce ultra-pure products for pharmaceutical drugs. Under terrestrial conditions, gravity introduces flows which mix and disperse components of a solution. For molecules with nearly the same charge, the fluid movement is a more powerful influence than the electric field. Microgravity virtually eliminates these flows, making possible more thorough separation, and thus, more pure materials. On IML-2, electrophoresis separation experiments on biological materials were carried out using two experiment facilities: the Applied Research on Separation Methods Using Space Electrophoresis (RAMSES), developed by CNES, and NASDA's Free Flow Electrophoresis Unit. Experiments were performed on proteins, pituitary cells and granules, the chromosome DNA of a nematode, culture solutions of animal cells and on sample distortion effects during separation.

C. Fluid Physics

Fluid and interfacial transport processes are common to both materials and biological systems. Under terrestrial conditions, the effect of gravity on inhomogeneous fluids generally results in internal phenomena such as buoyancy-driven convection, particle sedimentation as well as the distortion of fluid interfaces. These effects can add complexity to fluid systems. For example, the effects of other contributing processes (such as diffusion) can be masked or substantially modified. Thus, the microgravity environment affords the opportunity to study these other processes without the complicating influence of gravity.

Several studies took place in the Bubble Drop and Particle Unit that was flown on IML-2. Researchers examined bubble growth and interactions with solidification fronts, and the interactions between thermocapillary migrating bubbles and drops. In addition, the nature of convection driven by thermally induced interfacial tension gradients at interfaces in layered fluids was examined. In order to better understand the nature of the boiling process, nucleation, bubble growth, interfacial micro-layer, evaporation and condensation kinetics experiments were also carried out.

In addition to non-isothermal fluids, isothermal fluids were also the subject of BDPU investigations. Experiments on the static and dynamic behaviour of liquid in corners, edges and containers were undertaken in order to better understand wetting phenomena.

The critical dynamics of fluids were studied on IML-2 and USMP-2. At the critical point, the material fluctuates back and forth in small volumes from the liquid to the gaseous state such that the state of the total volume is indeterminate. In Earth's gravity, these experiments are difficult to perform due to the high compressibility fluids at the critical point. Most of the sample cannot be maintained at the critical density because the fluid is compressed by its own weight such that its density exceeds the critical density. The most critical region literally collapses under the weight of the fluid. Understanding how matter behaves at the critical point can provide insight into a variety of physics problems ranging from phase changes in fluids to magnetization changes in solids.

On USMP-2 and IML-2, density fluctuations near the critical point were measured using laser light scattering and interferometry. The behaviour of xenon was studied on USMP-2. On IML-2, the Critical Point Facility (CPF) was used to study the "piston effect." The piston effect refers to heat transport occurring at a typical time range of between a hundredth of a second and 30-50 seconds, depending on the actual temperature relative to the fluid's critical temperature. This can be compared to "acoustic time", based on the velocity of sound (in the range of only a few microseconds) and "diffusion time" (on the order of hours or even days for a substance near its critical temperature). The typical time for the piston effect is much longer than acoustic time, but shorter than diffusion time. The timescale of the piston effect is significant because thermalization, the process of a local temperature change becoming uniformly distributed, occurs on these timescales. For supercritical fluids, thermalization timescales correspond to the characteristic time of the piston effect. Other experiments in the CPF on IML-2 involved the study of heat transport and density fluctuations and density equilibration time scales in critical fluids.

Fluids experiments on IML-2 also included g-jitter studies in the Vibration Isolation Box Experiment System (VIBES). The experiments studied how g-jitter affects natural fluid flows, diffusion and thermally driven fluid flows under microgravity.

D. Combustion Research

The availability of improved low gravity facilities such as drop tubes and towers, parabolic flights and manned space missions offers unique opportunities and challenges to combustion science and technology. The reduced gravity levels afforded by these low gravity environments enable the study of combustion phenomena that, under terrestrial conditions, are obscure or substantially modified by gravitational effects. These research opportunities facilitate work toward the challenging task of developing strategies for the prevention and control of fire and explosion hazards for spacecraft.

Microgravity conditions for experimentation in combustion offer a variety of simplifications compared to terrestrial experimental conditions. These include a reduction in dimensionality, the inhibition of settling effects for multi-phase phenomena, and a substantial reduction of buoyancy forces. Studies focus on the processes of ignition, flame spreading, flame extinction, flamefront instabilities, smoldering, flammability limits of gaseous pre-mixed flames, and soot processes in non pre-mixed flames. In addition, materials synthesis in heterogeneous pre-mixed flames has also been considered. In many cases these experiments are of short duration. Short duration combustion experiments have been performed during 1994 in microgravity facilities such as the drop shafts at NASA Lewis Research Center in Cleveland, United States, and at Kamisunagawa in Japan and the drop tower in Bremen, Germany, as well as on parabolic flights.

VIII. SATELLITE DYNAMICS

The study of satellite dynamics is used to improve knowledge of the orbit perturbation model and results in better definition of the Earth's gravity and tidal models and its orientation, as well as the position of tracking sites and the satellite. The instrumentation currently being evaluated for obtaining precise orbits includes: the international Satellite Laser Ranging (SLR) network, the United States-developed Tracking and Data Relay Satellite System (TDRSS) and GPS, the French Doppler Orbitography and Radiopositioning Integrated Satellite (DORIS) and the German Precise Range and Range-rate Equipment (PRARE) system. Earth satellites currently using this instrumentation include Topex/Poseidon with SLR, GPS and TDRSS capabilities, and Meteor-3 with SLR and PRARE. The Laser Geodynamics Satellites (LAGEOS) I and II, STELLA, STARLETTE, ETALON-I and ETALON-II, Meteor-2 and AJISAI are only tracked by SLR systems. A significant portion of the session of the Panel on Satellite Dynamics at the 30th COSPAR Scientific Assembly was devoted to the determination and comparison of precise orbits using this instrumentation.

A. New Geodetic Satellites

In March 1994, the second United States GPS spacecraft equipped with a laser retroreflector array was launched, to provide SLR orbit determination to help assess the quality of GPS orbit models. MSTI-2, a new United States satellite, was maneuvered into a 425 km altitude, 97 degree inclination circular orbit, in May 1994. SLR tracking observations of this spacecraft will be used for atmospheric studies, as well as to improve the spatial resolution of existing static and dynamic gravity field models of the Earth. In early 1995, the German GFZ-1 satellite is scheduled to be launched from the Russian Federation Mir Space Station. It is a retroreflector satellite and the SLR data from this low altitude satellite orbit will also be used for gravity model and atmospheric drag studies.

B. New Geopotential Models

Several advances in gravity field modeling have been made during 1994. The JGM-3 model developed by the Goddard Space Flight Center and CSR has demonstrated notable improvement in the precise orbit determination of all currently orbiting geodetic satellites. New data include SLR and DORIS observations from Topex, SLR data on STELLA and LAGEOS-II, and for the first time GPS data from TOPEX. The GRIM-4 series of long wavelength global gravity field models has been derived from optical, laser and Doppler tracking data from 30 different satellites. The GFZ and CNES/GRGS groups which cooperate in the generation of these gravity fields have recently incorporated GEOSAT altimetry, GPS Topex/Poseidon satellite-to-satellite tracking as well as ERS-1 and TOPEX cross over differences.

C. Improved Terrestrial Reference Frame

The International Earth Rotation Service (IERS) generates improved definition of the Conventional Terrestrial Reference System (CTRS), based on contributions from many space measuring techniques such as SLR and VLBI. This year, IERS again will have a complete year of GPS data from a global network (IGS) of tracking stations to incorporate into a new CTRS definition. The analysis of SLR data, collected by a global network of laser ranging stations make significant contributions to the definition of the CTRS by defining its origin and scale. Many international groups are involved in this analysis of the various data types. An important goal is the maintenance of the positions for the global International GPS Service (IGS) network in coordination with FLINN fiducial network to the centimetre level. Considerable progress has been made towards this goal. The coordinates of the pole and universal time are currently being determined with an accuracy of 0.2 milliarcsecond and 0.05 millisecond, respectively.

D. Applications of GPS to Geodynamics

As of October 1994, there were 26 operational GPS spacecraft. This constellation has been declared operational and, as of 30 January 1994, anti-spoofing has been permanently turned on. This year also marked the first full year of the operation of a global tracking network which the IGS has established under the auspices of the IAG. There are now more than 50 globally-distributed high quality GPS receivers operating continuously. The tracking data are transferred through computer networks to several processing centres which generate precise orbits and Earth rotation parameter products within a few days after the data are made available. The 30 cm accuracy of the recovered orbits is quite an improvement over the accuracy of the broadcast ephemerides. The quality of the polar motion parameters is comparable to SLR, but the temporal resolution is higher, due to the continuous tracking coverage. The improvements in GPS orbit accuracy and the global coverage have also resulted in better results for the station position estimation. The United States JPL has reported IGS station position precision of a few cm. For a regional network, the GPS station position precision has been shown to be better than 1 cm, which is of importance for regional geodynamic studies.

As a complementary technique to SLR and VLBI, GPS promises to provide improvements to the temporal and spatial resolution of the geodynamic networks. In 1994, there were significant improvements in the automation of the techniques to handle the vast amounts of tracking data and the merging of the individual centre's products into a single product. The last two GPS satellites launched in August 1993 and March 1994 respectively, carry Laser Retroreflectors (for SLR) and for the first time we are in the position to compute GPS orbits for these spacecraft utilizing a very precise independent technique.

E. Satellite Missions to the Moon, Mars, and the Asteroids

The United States Clementine spacecraft successfully mapped the Moon for more than two months, from 19 February 1994 to 4 May 1994. The spacecraft failed before its attempt to fly-by the asteroid 1620 Geographos was accomplished. It carried a suite of instruments, including a laser altimeter for measuring lunar topography, and an S-Band transponder for studying the lunar gravity field. During its mapping of the Moon, Clementine also acquired 360,000 S-Band Doppler observations. These Doppler data now provide the strongest constraint on the lower degree portions of the lunar gravity field. The Clementine data were combined with 294,000 historical observations from the United States lunar orbiters 1 through 5 and the Apollo-15 subsatellite to determine a new model of the lunar gravity field. The Clementine spacecraft also carried other instruments, including a suite of cameras that acquired over one million images of the Moon. The United States Congress approved a new start for the Mars Global Surveyor spacecraft. This mission, a replacement for the Mars Observer spacecraft lost en route to Mars in 1993, will be launched in November 1996 a Delta launch vehicle. Mars Surveyor will arrive at Mars after a ten month cruise phase, in September 1997. The spacecraft will first be placed into a highly elliptical orbit with a period of 48 hours, and an apoapsis of 56700 km. Over a period of 146 days, the spacecraft orbit will be gradually lowered and circularized using aerobraking. Mars Global Surveyor will be the second interplanetary spacecraft to use aerobraking to change its orbit. Use of aerobraking means that less fuel and a smaller (and cheaper) spacecraft can be used. Aerobraking was successfully used on the Magellan spacecraft in orbit around Venus to change its orbit from an elliptical to a near low-altitude circular orbit. The Mars Surveyor will eventually reach a near-circular polar orbit at a mean altitude of 400 km.

The spacecraft is designed to map Mars for over one Mars year (687 days or through 2000). NASA has begun the full-scale development of a spacecraft to rendezvous with an asteroid. The mission, designated Near Earth Asteroid Rendezvous (NEAR), will be launched in February 1996, and will arrive near the asteroid Eros in December 1998. The spacecraft will orbit Eros for a year at altitudes as low as 24 km. Eros will be the smallest solar system body ever orbited by a spacecraft. Eros is a near-Earth asteroid, whose orbit regularly crosses the orbit of the Earth.

The instruments on NEAR include an X-ray and gamma ray spectrometer, a magnetometer, a near infrared spectrograph, a multi-colour camera, and a laser altimeter. En route to Eros, NEAR will fly by the asteroid Ilya in August 1996, and obtain a gravity assist from the Earth in January 1998. The spacecraft is being built by the Applied Physics Laboratory (APL) of the Johns Hopkins University in the United States. Mission operations will also be managed by APL.

IX. SCIENTIFIC BALLOONING

The success rate in scientific ballooning in 1993 and 1994 was close to 100 per cent. At the 1994 COSPAR conference, United States and French groups reported 99 per cent success rates for zero-pressure balloon flight data over the past several years. This remarkable result is due to continuous efforts to improve balloon materials, structural studies and manufacturing technologies, which have been undertaken in France, the United States, China, India, and the Russian Federation. Larger size balloons of 0.2 to 1 million m^3 with payloads of 2-3 tonnes are becoming common, even though smaller balloons are still quite useful for scientific observations by light weight payloads. These improvements in balloon technology were the basis of successful balloon campaigns in various locations in the world.

Advancements in NASA balloon research and development have continued with significant technical advances in the structural design and analysis of balloons, vertical flight performance modeling, materials characterization, materials development and processing, and the development of automated flight control hardware and software. A finite-element structural analysis capability has been developed for predicting the stress state in fully-inflated balloons by using the code ABAQUS, a commercially available, non-linear finite element code. Models of off-design balloon shapes have also been developed for constructing a balloon shape based on the inextensibility of the balloon film, preservation of balloon surface area, and a set of rules indicating how excess material must fold away. Preliminary results have been encouraging and have yielded shapes that are similar to real balloons.

Recent work has also established that fracture toughness, a material property that quantifies the ability of a material to resist the propagation of a flaw such as a tear or a hole in the balloon film, is a characteristic of polyethylene. Fracture toughness seems to be independent of sample geometry and thickness effects as a function of temperature. Current work is focused on determinations of the fracture toughness for six balloon films, and there is hope of being able to quantify the desirable properties for a successful film.

A prototype of an automated heat-seal-flaw detector system was completed in early 1994. This system uses both optical transmissivity and feature recognition to alert the operator of a potential flaw. The prototype has operated well in trial production runs, and the system will be production-tested on NASA balloons during the coming year. The production tests are intended to provide experience with the system's usage, to assess the "capture rate" of detectable flaws, and to help fine-tune the system.

A centralized library, designed to provide an accessible, comprehensive repository of scientific balloon technology information, is being established at the NASA Goddard Space Flight Center/Wallops Flight Facility at Wallops Island, Virginia. The library is expected to be completed late 1995.

The payloads from the successful 1991-1992 European Arctic Campaign were recovered in Sweden, Finland and Russian Federation. European groups are providing balloon-borne light payloads which can make future observations with small balloons in cooperation with satellites for magnetospheric and solar wind studies, such as Cluster, Interball and Polar, to be launched in 1995 and 1996. An Austrian group is providing small payloads for the observation of X-rays, electric fields and magnetic disturbances.

Long duration flights of balloons are another goal of balloon technology. Various efforts have been undertaken in two categories: the improvement of balloon systems to reduce ballast consumption, and methods to provide a long telemetry range and a wide recovery area for transoceanic or transcontinental flights.

The United States balloon programme, managed by NASA, has reported improvements in current capabilities and development of some new capabilities, particularly in the area of long-duration flights. Satisfying the scientific requirements has resulted in an increasing number of launches from remote sites. During the past year, flights were conducted from five sites including Palestine, Texas; Wallops Island, Virginia; Ft. Sumner, New Mexico; Lynn Lake, Manitoba, Canada; and MacMurdo Station, Antarctica. Since 1990, the MacMurdo site has been used annually for two long-duration flights, lasting from 9-14 days.

Super pressure balloons were supposed to be the most orthodox systems to save ballast. However, because of technical difficulties, they were only feasible for smaller balloons of less than 10000 m^3 with small payloads. Many feasibility studies to improve balloon structures and materials have been performed in these years, mainly by French and United States groups. The United States has succeeded in floating small super pressure balloons made from nylon biaxially-oriented film.

Over pressure balloons are less pressurized compared with super pressure balloons, but they still maintain the capability to save ballast depending on the degree of over pressure. A United States group has succeeded in flying an over pressure balloon and achieved a flight duration of about 50 hours. The size of the balloon was 0.8 million m^3 with a payload of 1,300 kg, and it was launched at Lynn Lake, Manitoba, Canada, in 1993. The result demonstrated that this system, after further improvement, provides a great possibility for long duration flight systems. One of the major difficulties is the large stress acting on the balloon film when the balloon is over pressurized. A Japanese group has conducted a structural analysis and reported that a pumpkin shaped balloon is more suitable for over pressure balloons than the zero-pressure shaped balloons now being used by the United States group.

Another approach for saving ballast is to control the thermal environment of the balloons to prevent the cooling of helium gas inside the balloons after sunset. The most successful approach up to now has been the system of an infrared Mongolfiere proposed by a French group some years ago. This is essentially a hot air balloon heated by the infrared radiation from the ground. The French group has been performing campaigns in the southern Pacific and Indian oceans with several balloons each year and test flights in the Arctic. The most recent results are from 60-day flights with 50 kg payloads. The balloon made altitude excursions of 17-30 km over the Indian Ocean. The French group is designing another type of helium filled balloon with thermal caps, in which gas cooling is prevented by the infrared radiation from the ground after sunset.

Japanese groups are also investigating the usage of new balloon films (ethylene-vinyl-alcohol) which preferentially absorb the infrared radiation from the ground at balloon altitudes, noting a possibility of reducing ballast consumption in long duration flights.

Satellite links for telemetry and positioning are generally employed in transoceanic and transcontinental flights. The satellite systems used include Argos, ETS-V, TDRSS and the Inmarsat standard C platform, all of which, except Argos, allow two-way communications. GPS is also widely used for balloons.

NASA has successfully completed a qualification/test flight of the non-polar long-duration balloon support system. This system provides for over-the-horizon commanding and telemetry through both the NASA TDRSS and the Inmarsat system: it also provides for autonomous balloon altitude control.

Trans-Mediterranean flights in Europe have been carried out each year through a collaborative programme between Italy, France and Spain, with payload recovery taking place in Spain. Almost ten flights are scheduled each year and the flights last more than ten hours each.

A group in the Russian Federation has also been operating long duration flights from Kamchatka to Ural lasting about 5-6 days. Another international effort is the collaboration with China, launching balloons from Beijing, and recovering the payloads in the western part of Russian Federation. These flights last almost four days. It is planned to launch 2-3 balloons each year.

Since there are no sunsets in the polar region during summer, one can expect long duration flights without ballast consumption for zero pressure balloons. The balloons are also expected to return to the launch area, since a circum-polar flow of high altitude winds exists in the polar region in summer. The season of circum-polar high altitude winds in Antarctica is limited to between mid-December and late January.

NASA has conducted an Antarctica campaign over the past two years. The balloons were launched from the MacMurdo Station and floated for nearly 10 days in circum-polar flights before returning to MacMurdo, where the payloads were recovered. The most recent results are from two flights launched in 1993 and 1994. The payloads were instrumented to observe the extremely high energy events of cosmic rays, and almost 250 hrs/m² exposure was achieved in each flight. The exposure time of one flight even corresponds to almost the total exposure of the experiment in the past ten years, which clearly demonstrates the efficiency of this circum-polar flight. Because of the marvelous success of long duration flights in this programme, NASA is planning to perform a long-term programme for long duration flight observations. The programme, called GOAL, will observe solar phenomena and the high energy cosmic ray spectrum at extremely high energy levels, which could not be achieved other than by such extremely long lasting observations. Because of the high operational costs of Antarctic flights compared to other space programmes, it is hoped that this programme will be extended in the near future. The Antarctica flights will undoubtedly open a new era of scientific ballooning for space exploration.

Besides the flights mentioned above, a group from the United States has launched small super pressure balloons of about 7000 m^3 to make precise observations of the atmospheric electric field at a constant altitude of 25 km. They have launched four balloons from New Zealand with flights of 2-4 months each, and successfully obtained valuable information in the respective field.

There are several future transoceanic and transcontinental flights under consideration. One of these is a campaign between the United States and Russian Federation, with launches from Canada and payload recovery in Greenland. The first flight is scheduled for 1995. As an extension of the existing Chinese-Russian Federation programme, two feasibility studies are in progress. Bulgarian, Chinese and Russian Federation groups have reported on the possible extension of the flights from Beijing to the Mediterranean and the recovery of the payloads in Spain. Another programme discussed by Chinese and Japanese groups implies balloon launches from Wakkanai, located in northern Hokkaido, Japan. According to meteorological feasibility studies of the balloon trajectories, the balloons will fly over northern China, Mongolia and the Russian Federation.

A group in India has also conducted feasibility studies for several transoceanic flight programmes. One is aiming at balloon launches from Andaman Island, where a tracking station for satellites is already established, and payload recoveries in southern India. Another study addresses launches from Hyderabad where a permanent balloon facility is located, flights over the Arabian sea, and recoveries in the East African area. The balloon group in India is quite active and performed almost 500 balloon launches since the Hyderabad station was established.

Many international collaborative programmes have been conducted, taking advantage of the high energy magnetic cut-off of Hyderabad, and ingenious observations of cosmic rays, X-rays, gamma-rays, infrared radiation, etc., have been performed.

Because of the nature of scientific ballooning, international collaboration in this field is indispensable. Besides those mentioned above, cooperative programmes between Australia and France, Brazil and the Russian Federation, Brazil and Japan, India and the Russian Federation, Japan and the United States and many European countries, have been effectively performed in recent years.

For example, a group in the Russian Federation observed various phenomena under the Brazilian magnetic anomaly, and a Japanese group has performed precise measurements of pulsed hard X-rays from PSR1509-50, Vela pulsar, as well as Cen-A and the galactic centre with sophisticated detectors under its collaboration with Brazil.

In a recent Japan-United States programme, balloon experiments of a super conductive magnetic spectrometer were performed from Lynn Lake, Canada, in 1993 and 1994. The size of the super conducting solenoid magnet is 1.5 m in length and 1 m in diameter, which gives almost ten times the effective area compared to any similar device ever floated. At the 1994 COSPAR meeting, it was reported that candidates of primary low energy anti-protons in cosmic rays, the flux of which has been given only an upper limit up to now, have been found.

During 1995, NASA's balloon programme will undergo a thorough re-evaluation. This will include an assessment of ballooning operations and the science payload requirements. For most disciplines, the expectation is that the flight rate will remain nearly constant or decrease slightly, although a few disciplines, such as infrared astronomy, expect a modest increase. The infrared discipline is building some new payloads to take advantage of both the LDB capability and new instrument technologies which have improved dramatically over the last several years. There is a strong preference to fly these new payloads in Antarctica, because of the favourable environmental conditions, e.g., low humidity and uniform surface albedo.

X. SPACE RESEARCH IN DEVELOPING COUNTRIES

During 1994, a major activity of the COSPAR Panel on Space Research in Developing Countries (PSRDC) was the organization of a meeting on the "Role of developing countries in ground-based experiments in support of space observations for global and regional change studies," which was held from 16-19 July 1994 as part of the 30th COSPAR Scientific Assembly. The main purpose of this meeting was to examine and promote, through invited presentations and discussions, certain new directions towards participation of developing countries in the interpretation of space-borne atmospheric and remote sensing data related to global and regional change through ground-based experiments that can be set up and maintained by countries with limited resources. The salient points of the deliberations of this meeting are summarized below:

A preparatory meeting of PSRDC members and participants was held on 15 July 1994 at Hamburg to discuss the main issues in introducing or strengthening space research activities in developing countries. The main points raised were: (a) scientific and applications related goals that can be achieved through space research; (b) major international programmes such as the International Geosphere Biosphere Programme (IGBP), World Climate Research Programme (WCRP), etc., and the role of the developing countries; (c) utilization of voluminous satellite/spacecraft data; (d) focussed activities related to region-specific problems such as meteorological phenomena of the equatorial region, volcanic aerosols, environmental degradation, etc.; (e) education and training programme; (f) funding support for travel; (g) enhancement of scientist-to-scientist interaction; (h) international collaboration; (i) political awareness of the benefits from space research; (j) regional/global campaigns to validate, supplement and complement space-based observations; (k) free access to data banks; and (l) organization/participation in special workshops/symposia.

The deliberations of the PSRDC meeting started with the introductory remarks of Dr. K. Kasturirangan (India), Chairman of PSRDC, and a keynote address by Dr. H. Curien (France). Dr. Kasturirangan mentioned that one of the main objectives of organizing such a meeting was to examine various possibilities and avenues that exist in promoting space research in developing countries and making it politically, socially and economically viable. Out of several themes that may be applicable, the present theme on global/regional change studies was selected to demonstrate the role that the developing countries may play in this field of research. Dr. Curien stressed that while satellite observations are plentiful, corresponding ground measurements are not adequate because specific budget provisions (in developed countries) are made only for the former. Hence, the developing countries can play a significant role by setting up, operating and utilizing ground-based systems and reaping the benefits from both the ground and space segment data. Such experiments are essential for investigations related to climate change, management of agriculture, occurrences of natural catastrophes, etc. The present lacunae need to be erased by providing suitable forums for discussions/presentations, communication networks, data accessibility, exchange/arrangements for reciprocal visits, training facilities, etc.

The presentations to the meeting were divided into the following categories: (a) the scope, content and suggestions to initiate space research in developing countries; (b) satellite data sets and ground-based experiment needs in developing countries; (c) international experience; (d) the experience of the developing countries; and (e) promotional possibilities.

Dr. J.G. Roederer (United States) mentioned that the complex interactions between various processes in the geosphere-biosphere sets intrinsic limits to its predictability but that the developing countries can play a crucial role by providing human talent, geographic coverage and hard work for the daunting task of monitoring and interpreting the system under study. He emphasized the need to reverse the present trend in lack of support for basic space science research having long-term implications for our understanding of the Sun-Earth system. Prof. H.J. Bolle (Germany) highlighted the problem of energy and water exchange between soil, vegetation, and the atmosphere which, to a large extent, determines the regional climate and depends on land use changes and desertification. For such studies, it is essential to have collateral ground-based observations along with satellite data for repetitive and homogeneous global coverage. The ground-based data enhances the reliability and interpretation of satellite data. For the implementation of its activities, IGBP has launched the System for Analysis, Research and Training (START) project which is meant to establish regional research centres connected to the research sites within the region. He suggested that "Anchor Stations" should be set up that allow information derived from the satellite measurements to be controlled and its quality improved. At these stations certain key parameters, such as radiometric properties of the surface, energy budgets and the state of vegetation should be measured. The combined ground-based and satellite information may then be transmitted to regional users and through regional START centres to modelling centres. Dr. J.L. Fellous (France) described the status and achievements of the MEDIAS (establishment of a Regional Research network for the Mediterranean Basin and the Subtropical Africa) programme which has been undertaken in close collaboration with START. The main objective of this programme is to involve scientists from developing countries to contribute to ground-based, long-term monitoring of precipitation, ozone, aerosols, etc. for combining with global satellite observations.

Following the above review papers, more specific examples of the complementary nature of the ground-based data in association with global satellite observations were presented in the next session entitled "The satellite data sets and ground-based experiment needs in developing countries." Dr. T. Konig (Germany) highlighted the use of ERS-1 data for environmental applications in which developing countries could participate. He mentioned the German collaboration and involvement of the National Institute for Space Research (INPE), Brazil, for investigations of inventory campaign with radar remote sensing in the tropical rainforest. Such studies of dynamics of forest systems are planned using German ERS-1 and ISIS satellite data at radio and optical frequencies. Dr. S.C. Chakravarty (on behalf of Dr. K. Kasturirangan, India) presented examples of the use of satellite vegetation index (VI) data derived from Indian and other remote sensing satellite observations (i.e. from IRS-1A, IRS-1B, INSAT, LANDSAT, SPOT, NOAA, etc.) and concurrent ground-based measurements in various application oriented projects carried out by Indian scientists. The vegetation cover of the Earth's surface is an important parameter, which modulates exchange of momentum and heat fluxes between surface and the atmosphere. Demonstration results were presented on the relationship between changes in VI and environmental parameters such as net primary productivity, atmospheric CO_2, forest fire/deforestation, crop pattern dynamics, agricultural droughts, rainfall anomalies, etc. Dr. T. Ishiyama (Japan) described the experiment of spectral reflectance measurements of soil and plant species around the Taklimakan Desert in China using portable spectroradiometers in the range of 400-2500 nm. The shape of the spectral reflectance is the same for plant species but the reflectance levels are quite different. Soil and sand reflectance shows gradual increase with increasing wavelengths. The effect of soil moisture content on reflectance is large in the 1450 and 1950 nm spectral bands. It was concluded that the absolute radiance values of satellite data should be used to derive the soil moisture content. Dr. P.J. Crutzen (Germany) outlined the need for a better assessment of variations, both for stratospheric and tropospheric ozone concentrations, particularly over the tropics where the observations are inadequate. Tropospheric ozone concentrations may change due to excessive biomass turning, industrial activities, etc. He suggested that an international programme be initiated for tropospheric and stratospheric ozone measurements with a network of observing stations.

The next session dealt with "The satellite data sets and ground-based experiment needs in developing countries." Dr. S.I. Rasool (France) provided vital information on the availability, at reasonable cost, of global vegetation maps from NOAA-AVHRR data through November 1994 on CD-ROMs. Many global change studies are planned using the satellite data on seasonal/annual variations of vegetation cover, biomass burning estimates, extent of wet lands, surface albedo, net primary productivity, etc. He emphasized the critical requirement of ground validation of these data products at globally distributed sites. Dr. J.P. Burrows (Germany) mentioned that, along with the atmospheric simulation studies for global change programme, there is a need to provide observational data for the minor atmospheric constituents such as ozone, water vapour, carbon monoxide, aerosols, etc. This will also provide a detailed knowledge of the temporal variability of the atmospheric composition. It is important to have measurements on the vertical and horizontal distribution of trace gases, clouds, aerosols and physical parameters such as temperature, pressure and surface spectral reflectance. This would be best provided by a mixture of ground-based, shipboard, aircraft and satellite observations.

Under the session "International experience in developing countries," Dr. R.J. Coullahan (United States) presented the efforts through the Socio-econometric Data and Applications Centre (SEDAC) of the Consortium for International Earth Science Information Network (CIESIN) in making the data and information of the human dimension in global change studies available to scientists in developed and developing countries. The data are presently made available through electronic networks such as the Internet. CIESIN is creating a distributed data archive called Information Cooperative that links data resources stored in the United States, Europe, Africa, Latin America and Asia in a single data sharing system. Dr. A.P. Mitra (India) provided detailed information on START, including its main objectives, structure and present status. He described the START programme in Africa and Asia including the identified Regional Research Centres and the formation of the Regional Networks for research sites.

Under the session on "The experience of developing countries," a number of presentations were made to demonstrate the experience of developing countries in experiments involving ground-based observations and satellite data to investigate the global change phenomena. Dr. K. Kasturirangan (India) presented sample results of a number of studies carried out in India using indigenously built satellite series such as IRS, INSAT and SROSS, as well as foreign satellites such as NIMBUS, LANDSAT, SPOT and ERS along with concurrent ground-based measurements. The topics of such investigations include forest cover and volume, crop yield and biomass estimation, rainfall characteristics, evapotranspiration, soil moisture, snow melt run-off and sea-surface temperatures. Other areas of research include total ozone content and ground research, solar B-UV fluxes, aerosol distribution and its impact during major volcanic eruptions, methane emission from rice paddy fields and the electrodynamics of ionospheric plasma and generation of spread-F irregularities. Dr. M.E. Machado (Argentina) reported Argentina's plan to launch its first satellite, SAC-B, carrying astrophysical payloads, to be followed by SAC-C, which would be devoted to remote sensing to study agricultural efficiency, forestry, desertification control areas, biomass quantity, etc. Ground-based measurements already carried out in past decades and relevant to satellite-based studies were presented pertaining mainly to flood zoning using topographical data and satellite remote sensing observations. Dr. M.A. Abdu (Brazil) presented a number of initiatives taken by Brazil to investigate the problem of global and regional change. With the launch of the first Brazilian satellite SCD-1, a network of DCPs are being activated at a number of sites in the Amazon region to monitor ozone, carbon dioxide, UV-radiation, etc. The data collected from these DCPs, along with satellite remote sensing imagery/radiance data and other ground based laser, optical and radio observations, would provide important information on long-term changes taking place in the region.

Dr. Hau-Ren Pan (China) highlighted China's efforts in pursuing studies ensuring comprehensive utilization of space data and related ground-based observations. In the absence of a national long-term satellite for remote sensing applications, the imported LANDSAT imageries and NOAA data have been utilized along with airborne SAR, balloon, sounding rocket, buoy, GPS networks, etc., for deriving maximum scientific output from satellite data. Airborne SAR and related ground-based measurements were carried out synchronously with the data from the Space Shuttle's SIR-C/X-SAR imaging radar. The airborne SAR has been used to pick up natural disaster events and transmitted through satellite to the disaster control headquarters. Dr. A. Singh (UNEP) mentioned UNEP's efforts to promote ground-based measurements of key environmental parameters in developing countries. Dr. J. Soegijo (Indonesia) presented the unique geographical and environmental situation of the Indonesian archipelago for conducting global change and related studies. The main concern is the increase in greenhouse gases which may lead to global warming and sea level rise. He emphasized the need for international collaboration in undertaking projects involving satellite, balloon and ground-based observations. An International Centre for Equatorial Atmospheric Research (ICEASR) has been established which will have an equatorial radar as its major facility.

Dr. A. Abiodun (United Nations Office for Outer Space Affairs) summarized the results of a questionnaire sent to the concerned agencies in developing countries on their current plans of research activities in the field of global change and applications of remote sensing data. He observed that there is no set of standard ground-based monitoring instruments which may be operated in a global network for validating satellite remote sensing data for global change studies. He noted that under United Nations auspices, several Centres for Space Science and Technology Education would be established in developing countries by September 1995 which will enable their enhanced participation in space-based research. Dr. Wayumba (Kenya) submitted a paper (not presented) stressing the need for training appropriate manpower for utilization of space-based remote sensing data in developing countries such as Kenya so as to facilitate greater participation in international ventures such as IGBP, etc.

In the poster session, Dr. T.L. Gulyaeva (Russian Federation) addressed the inadequacy of present ground-based ionospheric sounding data for deriving an ionospheric disturbance index similar to the geomagnetic disturbance index. She emphasized that developing countries may participate in the ground radio sounding data of the ionosphere to get involved in space research. Dr. Shin-Yi Su (Taiwan) presented Taiwan's low latitude ionospheric tomography network to study the large scale phenomena associated with the equatorial ionization anomaly, equatorial plasma bubble and equatorial electrojet. It consists of a chain of receivers with data acquisition system, receiving signals from UN-NNSS satellites. Fei-Bin Hsiao (Taiwan) presented a training tool for receiving micro-satellite data and ground simulation for image acquisition and image processing.

The above presentation was followed by the concluding session on "Discussion on promotional possibilities." Individual presentations were made by Dr. K. Kasturirangan (India), Dr. A. Singh (United States), Dr. A.P. Mitra (India), Dr. M.H.A. Hassan (Italy), Dr. R.R. Daniel (India), Prof. W.I. Axford (Germany), and Dr. A.A. Abiodun (United Nations) highlighting the efforts made by various international agencies in promoting space research in developing countries. These agencies include the UNEP, IGBP-START, Third World Academy of Sciences (TWAS), Committee on Science and Technology in Developing Countries (COSTED), COSPAR, and the United Nation's Committee on Peaceful Uses of Outer Space (UN-COPUOS). The following major suggestions were made as an outcome of these presentations and follow up discussions:

(a) Ground-based experiments, apart from their being useful on a stand-alone basis, contribute in complementing, validating and calibrating satellite borne observations which enhance the quality of scientific results;

(b) A number of space-based studies require the coordination of ground-based data collection on global scales, including:

- Inventory of greenhouse emissions
- Inventory and monitoring of biodiversity
- Terrain elevation maps
- Global Terrestrial Observing Systems (GTOS)
- Global Information System (GIS)
- World Climate Research Programme (WCRP)
- International Tropospheric Ozone Year (ITOY)
- International Geosphere Biosphere Programme (IGBP)

(c) There is a need to generate trained manpower through programmes such as START in developing countries who can initiate, plan and participate in the global change studies;

(d) Efforts should be made to ensure, at reasonable costs, easy availability of space-based data in standard formats for comparison and validation with ground-based data, as well as for pursuing global change studies;

(e) International collaboration between developed and developing countries would be an essential element for better exchange of ideas, utilization of facilities, training, joint investigations, etc.; and

(f) There is a need to improve communication through electronic media (e-mail, Internet, etc.) between research groups of different countries.

The PSRDC core group made the following recommendations on behalf of COSPAR for presentation to ICSU:. "The national members of COSPAR, ICSU unions and associated members should encourage and support programmes and activities involving ground-based and space techniques, particularly related to global and regional change studies and facilitate increased participation of scientists from developing countries."

During 1994, the Panel has extended travel support to scientists from developing countries to participate in scientific meetings, workshops, etc. on topics relating to space research. A large number of scientists from developing countries were provided financial assistance to participate in the PSRDC meeting held at COSPAR, Hamburg. For the purpose, COSPAR received financial contributions from UNEP, the United Nations Office for Outer Space Affairs, COSTED and TWAS.

CONTRIBUTORS

The report submitted by IAF (Part One) was prepared by Dr. Jerry Grey (for J. Hess and J. Runavot, Co-Chairmen of the International Programme Committee for the 45th IAF Congress) and was approved by Karl Doetsch, President of IAF. The IISL contribution on space law and international cooperation was prepared by IISL Secretary, Tanja Masson-Zwaan.

For the report submitted by COSPAR (Part Two), each of the organization's Interdisciplinary Commissions and Panels contributed a chapter. The following individuals prepared material for their respective Commission or Panel: Dr. J. Schmetz (ESA/ESOC), coordinator for Chapter I; Dr. C. Albanesi (Italy), Dr. C. Boalch (United Kingdom), Dr. S.C. Chakravarty (India), Dr. J. Chambers (Canada), Dr. V.S. Etkin (Russia); Ms. M.A. Haren (United States); Dr. A. Mahmood (Canada); Dr. T. Moriyama (Japan), Dr. A. Richardson (United Kingdom), Mr. M. Saiki (Japan), Dr. R.S. Winokur (United States), Mr. Jianmin Xu (China), and Prof. R.-L. Xu (China), contributors, Chapter I; Prof. D. Möhlmann (Germany), coordinator for Chapter II; Prof. E. Grün (Germany) and Prof. T.C. Owen, (United States), contributors, Chapter II; Prof. E.V. Thrane (Norway), coordinator for Chapter III; Dr. D. Bilitza (United States), Prof. A. Manson (Canada), Dr. V.I. Moroz (Russia), Prof. A.F. Nagy (United States), Dr. K. Oyama (Japan), Dr. D. Rees (United Kingdom), Prof. F.W. Taylor (United Kingdom), and Dr. D. Titov (Russian Federation), contributors, Chapter III; Dr. G. Paschmann (Germany), coordinator for Chapter IV; Dr. D.E. Page (United States), contributor, Chapter IV; Prof. J.L. Culhane (United Kingdom), coordinator for Chapter V; Dr. E. Antonucci (Italy), Dr. S. Holt (United States), and Prof. G.G.C. Palumbo (Italy), contributors, Chapter V; Dr. J.D. Rummel (United States), coordinator for Chapter VI; Dr. D. Mesland (ESA/ESTEC), Dr. M. Meyer (United States), Dr. M. André (France), and Dr. F. Bréchignac (France), contributors, Chapter VI; Prof. J.I.D. Alexander (United States), coordinator Chapter VII; Dr. R. Kolenkiewicz (United States), coordinator for Chapter VIII; Dr. F. Lemoine (United States), Prof. H. Montag (Germany), Dr. R. Noomen (Netherlands), Dr. E. Pavlis (United States), and Dr. P. Schwintzer (Germany), contributors, Chapter VIII; Prof. W. Riedler (Austria), coordinator for Chapter IX; Prof. J. Nishimura (Japan), Dr. K. Torkar (Austria) and Dr. W. Vernon Jones (United States), contributors, Chapter IX; and Dr. K. Kasturirangan (India), coordinator for Chapter X; Dr. R.A. Harrison (United Kingdom), Editor. The report was approved by COSPAR Executive Director, Prof. S. Grzedzielski.

ACRONYMS AND ABBREVIATIONS

AADSF	Advanced Automated Directional Solidification Furnace
ADEOS	Advanced Earth Observing Satellite
Ajisai	(Hydrangea flower) Japanese geodetic satellite
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AMSU	Advanced Microwave Sounding Unit
APCF	Advanced Protein Crystallization Facility
ATLAS	Atmospheric Laboratory for Applications and Science
ATSR	Along Track Scanning Radiometer
AU	Astronomical Unit
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and New Infrared Radiometer
AXAF	Advanced X-ray Astrophysics Facility
BDPU	Bubble Drop and Particle Unit
CADRE	Coupling and Dynamics in Regions Equatorial
CCD	Charged Coupled Device
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEEF	Closed Ecology Experiment Facilities (Japan)
CELSS	Controlled Ecological Life Support System
CERES	Clouds and the Earth's Radiant Energy System
CIESI	Consortium for International Earth Science Information Network
CLUSTER	ESA S/C squadron to study Earth's magnetosphere
CNES	Centre National d'Etudes Spatiales
CNSR	Canadian Network for Space Research
COBE	Cosmic Background Explorer
CONAE	Comision Nacional de Actividades Espaciales (Argentina)
COSPAR	Committee on Space Research
COST	Commission on Science and Technology
COSTED	Committee on Science and Technology in Developing Countries
CPF	Critical Point Facility
CRISTA	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere
CSA	Canadian Space Agency
CSR	Center for Space Research (Univ. of Texas at Austin)
CTRS	Conventional Terrestrial Reference System
DAAC	Distributed Active Archive Center
DARA	German Space Agency
DCP	Data Collection Platform
DECIMALS	Dynamical, Electrical and Chemical Small-Scale Structure in Mesopause
DMSP	Defense Meteorological Satellite Program (United States Air Force)
DNA	Deoxyribonucleic Acid
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
DYANA	Dynamics Adapted Network for the Atmosphere

EISCAT	European Incoherent Scatter Facility
EOS	Earth Observing System
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETALON	Russian Federation geodetic satellite
ETS-V	Engineering Test Satellite (Japan)
EU	European Union
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUV	Extreme Ultraviolet
EUVE	Extreme Ultra-Violet Explorer
FAA	Federal Aviation Administration
FAST	Fast Auroral Snapshot Explorer
FIRST	Far Infrared Sub-mm Telescope
FLINN	Fiducial Laboratory for International Natural Network
FPI	Fabry-Perot Interferometers
FUSE	Far Ultraviolet Explorer
GEOSAT	Geostationary Earth-Orbiting Satellite
GEOTAIL	Satellite to study the Earth's magnetotail
GGS	Global Geospace System
GIS	Global Information System
GMS	Geostationary Meteorological Satellite
GOAL	Galactic Origin and Acceleration Limit
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ocean Monitoring Experiment
GPS	Global Positioning System
GRIM	German/French Global Earth Gravity Models
GRL	Geophysical Research Letter
GRO	Gamma-Ray Observatory
GSFC	Goddard Space Flight Center
GTOS	Global Terrestrial Observing Systems
GW	Gravity Waves
HESI	High Energy Solar Imager
HF	High Frequency
HIRS	High Resolution Infrared Radiation Sounder
HRDI	High Resolution Doppler Imager
HST	Hubble Space Telescope
IAG	International Association of Geodesy
IASTP	Inter-Agency Solar-Terrestrial Programme
ICE	International Cometary Explorer
ICSU	International Council of Scientific Unions
ICTP	International Center for Theoretical Physics
IDGE	Isothermal Dendrite Growth Experiment
IERS	International Earth Rotation Service
IGBP	International Geosphere-Biosphere Programme

IGS	International GPS Service
ILAS	Improved Limb Atmospheric Spectrometer
IMF	Interplanetary Magnetic Field
IMG	Interferometric Monitor of Greenhouse Gases
IML-2	International Microgravity Laboratory
IMS	Infrared Mapping Spectrometer
INMARSAT	International Maritime Satellite
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
INSAT	Indian satellite
IR	Infrared
IRI	International Reference Ionosphere
IRS	Indian Remote Sensing satellite
ISAS	Institute of Space and Astronautical Science
ISO	Infrared Space Observatory
ISRO	Indian Space Research Organization
ITOY	International Tropospheric Ozone Year
IUE	International Ultraviolet Explorer
IZMIRAN	Russian Federation Institute for Geomagnetism and Radio Wave Propagation
JATP	Journal of Atmospheric and Terrestrial Physics
JGM	Joint Gravity Model
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory
LAGEOS	Laser Geodynamic Satellite
LANDSAT	Land remote sensing satellite
LEGRI	Low Energy Gamma-ray Instrument
LIDAR	Light Intensification, Detection and Ranging
LIS	Lightning Imaging Sensor
LITE	Lidar In-space Technology Experiment
MAHRSI	Middle Atmosphere High Resolution Spectrograph Investigation
MF	Medium Frequency
MITI	Ministry of International Trade and Industry
MLT	Mesosphere and Lower Thermosphere
MLTCS	Mesosphere, Lower Thermosphere Coupling Study
MOPITT	Measurement of Pollution in the Troposphere
MST	Mesosphere/Stratosphere/Troposphere
MSTI	Military Seeker Technology Integration
NASA	National Aeronautics and Space Administration (United States)
NASDA	National Space Development Agency (Japan)
NCAR	National Center for Atmospheric Research
NDVI	Normalized Vegetation Index
NEAR	Near Earth Asteroid Rendezvous
NIMBUS	Weather satellite
NIMS	Near Infrared Mapping Spectrometer
NISSE	Norwegian Ionospheric Small Satellite Experiment

NLC	Noctilucent Clouds
NOAA	National Oceanographic and Atmospheric Administration (United States)
NSCAT	NASA Scatterometer
OCTS	Ocean Color and Temperature Sensor
PI	Principal Investigator
PMSE	Polar Mesosphere Summer Echoes
POLAR	NASA spacecraft to study polar magnetosphere
POLDER	Polarization and Directionality of Earth's Reflectance
PR	Precipitation Radar
PRARE	Precise Range and Range-rate Experiment
PRIME	Prediction and Retrospective Ionospheric Modelling over Europe
PSC	Polar Stratospheric Clouds
PSD	Panel on Satellite Dynamics
PSRDC	Panel on Space Research in Developing Countries
PULSAUR	Pulsating Aurora Rocket
RIS	Retroreflector in Space
RNA	Ribonucleic Acid
ROSAT	Röntgen Satellite (German X-ray satellite)
SAC-B,C	Satellite de Aplicaciones Cientificas (Argentina)
SAMPEX	Solar, Anomalous, Magnetospheric Particle EXplorer
SAR	Synthetic Aperture Radar
SAX	X-ray Astronomy Satellite
SCALE	SCAttering Layer Experiment
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SeaWIFS	Sea-viewing Wide Field Sensor
SEDAC	Socioeconometric Data and Applications Center
SIMURIS	Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy
SIR	Spaceborne Imaging Radar
SIRTF	Space Infrared Telescope Facility
SLR	Satellite Laser Ranging
SMM/I	Special Sensor Microwave/Images
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SPAS	Shuttle Pallet Satellite
SPOT	Satellite pour l'Observation de la Terre
SRL	Space Radar Laboratory
SROSS	Stretched Rohini Satellite Series
SSBUV	Shuttle Solar Backscatter Ultraviolet
SST	Space Solar Telescope
STARE	Scandinavian Twin Auroral Radar Experiment
STARLETTE	French geodetic satellite
START	System for Analysis, Research and Training
STELLA	French geodetic satellite

STEP	Solar Terrestrial Energy Programme
STP	Solar-Terrestrial Physics
TDRSS	Telemetry and Data Relay Satellite System
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics
TM	Thematic Mapper
TOMS	Total Ozone Mapping Spectrometer
TOPEX/Poseidon	Joint French/US altimeter satellite
TRACE	Transition Region and Coronal Explorer
TRMM	Tropical Rainfall Measurement Mission
TROV	Telepresence Remotely Operated Vehicle
TWAS	Third World Academy of Sciences
UARS	Upper Atmosphere Research Satellite
UNEP	United Nations Environment Programme
USMP-2	United States Microgravity Payload
UV	Ultraviolet
VHF	Very High Frequency
VI	Vegetation Index
VIBES	Vibration Isolation Box Experiment System
VIRA	Venus International Reference Atmosphere
VIRS	Visible Infrared Scanner
VLBI	Very Long Base Interferometry
WCRP	World Climate Research Programme
WIND	NASA spacecraft to study solar wind and terrestrial plasma
WIND II	Wind Imaging Interferometer
XMM	X-ray Multi-Mirror
XTE	X-ray Timing Explorer
XUV	X-ray and far Ultraviolet

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